Skin colour, photoprotective measures, and solar ultraviolet radiation exposure of workers on a macadamia nut and avocado farm

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Thesis submitted in fulfilment of the requirements for the degree Doctor of Philosophy in Occupational Hygiene at the North-West University

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Examination: December 2020

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This thesis is dedicated to my father Dries Linde and my two grandfathers, Lou Linde and Attie Venter who passed away during the time period that I have been busy with this degree. Although they could not be with me at the end of this journey, I will always be a product of all the lesson the taught me about perseverance and work ethic.

"*Ocean and star, each am I. Broken my wings and yet I fly*"

David Gemmell

ACKNOWLEDGEMENTS

I would like to thank the following people who supported me during the completion of this thesis:

- My family, in particular my mother Rianne, my brother Stefan and sister-in-law Janien. Your constant love and support lifted me when I needed it most.

- My extended family who provided encouragement as well as accommodation during data collection and introduction to the right people in the case of Louis Linde and Elsje Linde

- Prof. Johan du Plessis, for all your support and effort to make a long distance work supervision situation work. I truly appreciate everything that I have learned from you.

- Prof. Caradee Wright, for her expert guidance and support whenever needed during this whole process from start to finish.

- Prof. Sura Ellis, for assistance with the statistical analysis for this thesis.

- My University of Limpopo colleagues, especially my long distance PhD companions Jino Mundackal and Yvette Chetty who went on journey with me.

- Ms Cynthia Ramotsehoa for assistance with instrumentation and analysis of polysulphone badges as well as emotional support.

- Ms Thandi Kapwata for her assistance in data analysis etc.

- Mrs Venita de Kock from Words That Work Language Editing, for the language editing of this thesis.

- Jasmine, who was with me through everything

- All the farmworkers, supervisors, office staff and owner of the macadamia nut and avocado farm without whom this research would not have been possible.

ABSTRACT

Title: Skin colour, photoprotective measures, and solar ultraviolet radiation exposure of workers on a macadamia nut and avocado farm.

Background: Outdoor agricultural workers such as farmers and farmworkers have been identified as an occupational group that is at high risk of exposure to solar ultraviolet radiation (UVR) during their work activities. Outdoor workers' exposure to solar UVR need to be managed to prevent negative health effects such as skin cancer and ocular diseases. Skin colour and melanin content of skin provides a measure of genetic protection against exposure to high levels of solar UVR. Photoprotective measures such as wearing long sleeve clothing, broad-brimmed hats and sunglasses have been identified as measures that can reduce an individual's exposure to solar UVR if used correctly. The solar UVR exposure of outdoor farmworkers has not previously been investigated in South Africa.

Aims and objectives: The general aim of this thesis was to quantify the differences in skin colour and melanin content of facultative and constitutive skin of farmworkers on a macadamia nut and avocado farm in the Limpopo Province of South Africa, as well assessing the existing control measures and practices of those farmworkers together with their occupational exposure to solar UVR to determine if the exposure poses a risk to their health. The specific objectives were: (i) to determine the differences in skin colour (individual typology angle, ITA°) and melanin content (melanin index, MI) between the facultative and constitutive skin of farmworkers using skin bioengineering measurements, (ii) to assess the solar UVR practices, in particular the use of ocular protective measures, of the farmworkers on the farm using questionnaires, (iii) to determine the photoprotection provided by the clothing worn by farmworkers using polysulphone (PSF) badges on the shoulder both under and on top of the clothing and (iv) to assess the personal solar UVR exposure of outdoor farmworkers on the farm during autumn, spring and summer while carrying out their different work activities through polysulphone badges placed on their arms, top of the shoulder and top of any head covering worn.

Methods: Outdoor and indoor farmworkers on the farm participated in this study. The skin colour and melanin content of the skin of farmworkers were classified using both a subjective method, namely questionnaires and objective methods namely measurement of ITA°) and MI. Outdoor farmworkers' use of ocular photoprotective measures was determined with the use of a questionnaire. The photoprotection provided by the clothing worn by farmworkers was measured by placing a PSF badge on the shoulder beneath the clothing and on the outside

of clothing and classified according to the requirements of the AS/NZS 4399:2017 standard. The solar UVR exposure of outdoor and indoor farmworkers was measured by placing PSF badges on the shoulder, arm and top of the head during autumn, spring and summer during different work activities. Workers' exposure was compared with the highest value of the International Commission of Illumination (CIE) occupational exposure limit, namely 1.3 SED (standard erythemal dose). Research ethics approval for this study was obtained from the North-West University Health Research Ethics Committee (NWU-00101-17-A1).

Results: Significant differences were found between both the ITA° and MI measured on the constitutive (inner upper arm) skin and facultative (back of the hand) of farmworkers. The skin colour of the majority of farmworkers were objectively classified as falling in the Fitzpatrick Phototype V/Brown. A strong correlation was found between ITA° and MI which indicates that both objective methods are appropriate to determine the skin colour of darkly-pigmented skin. The majority of outdoor farmworkers (80%) never wore sunglasses while working outside. Although more than 70% of outdoor farmworkers wore a hat while working, they preferred to wear a cap rather than a broad-brimmed hat which provides better ocular photoprotection. Statistically significant differences were found between the solar UVR underneath and outside of clothing worn by farmworkers during autumn, spring and summer. Only 5% of clothing did not provide the minimum required photoprotection. More than 75% of farmworkers reported that they removed the long sleeve overall jacket they wear as part of their uniform at some point during the day which exposes their arms to solar UVR. Statistically significant differences were found between the solar UVR measured on the shoulder, arm and top of the head of outdoor farmworkers during spring and summer. The arm received the highest solar UVR exposure during autumn (7.8 SED) while the top of the head received the highest levels during spring (11.6 SED) and summer (13.9 SED). The solar UVR exposure of all body sites exceeded the daily CIE exposure limit for more than 80% of measurements during all three seasons.

Conclusion: Skin colour and melanin content of farmworkers in this study was found to provide a high level of genetic photoprotection. It was also found that objective and subjective measurement of skin colour and can both be used to classify the skin colour of an occupational group in order to identify genetic photoprotection in workers. The use of ocular photoprotective measures by the outdoor farmworkers in this study was inadequate. The clothing worn by farmworkers in the study provided sufficient photoprotection, but removal of clothing during the day decreased its effectivity. The exposure of farmworkers to solar UVR exceeded the recommended CIE exposure limit during not only summer, but autumn and spring as well

which indicates that photoprotective measures should not only be in use during summer but also during the other two seasons. The solar UVR exposure of the outdoor farmworkers included in our study was generally higher than the exposure of farmers and farmworkers in other countries. Finally, ten recommendations are made to the macadamia nut and avocado farm to reduce farmworkers' exposure to solar UVR. Limitations of this study were also identified along with recommendations for future studies.

Key words: agricultural workers, ultraviolet radiation occupational exposure, environmental health, skin colour, ocular photoprotective measures, photoprotective clothing.

OPSOMMING

Titel: Velkleur, fotobeskermende maatreëls, en blootstelling aan sonlig-ultravioletstraling van werkers op ’n makadamia neut en avokado plaas.

Agtergrond: Landbouwerkers wat buite werk, soos boere en plaaswerkers, is geïdentifiseer as ’n groep met ’n hoë risiko vir blootstelling aan son-ultravioletstraling (UVR) gedurende werksaktiwiteite. Werkers wat buite werk se blootstelling aan son-UVR moet bestuur word om die negatiewe gesondheidseffekte soos velkanker en okulêre siektes te voorkom. Velkleur en die melanieninhoud van die vel lewer ’n mate van genetiese beskerming teen blootstelling aan hoë son-UVR-vlakke. Fotobeskermende maatreëls soos die dra van langmouklere, breërandhoede en sonbrille is geïdentifiseer as maatreëls wat ’n individu se blootstelling aan son-UVR kan verminder as dit korrek gebruik word. Die blootstelling aan son-UVR van plaaswerkers wat buite werk is nog nooit vantevore in Suid-Afrika ondersoek nie.

Doelstellings: Die oorkoepelende doel van hierdie proefskrif was om die verskille in velkleur en melanieninhoud van fakultatiewe en konstitutiewe vel van plaaswerkers op ’n makadamianeut- en avokadoplaas in die Limpopoprovinsie in Suid-Afrika te kwantifiseer, en om die bestaande beheermaatreëls en gewoontes van hierdie plaaswerkers tesame met hulle beroepsblootstelling aan son-UVR te assesseer met die doel om te bepaal of die blootstelling ’n gesondheidsrisiko inhou. Die spesifieke doelwitte was: (i) om die verskille in velkleur (individuele tipologiehoek, ITA°) en melanieninhoud (melanienindeks, MI) tussen die fakultatiewe en konstitutiewe vel van plaaswerkers met die hulp van bio-ingenieursmetodes te bepaal, (ii) om die son-UVR-gewoontes, veral die gebruik van okulêre maatreëls deur plaaswerkers, te assesseer met behulp van vraelyste, (iii) om die mate van fotobeskerming wat deur die klere van plaaswerkers gebied word vas te stel deur polisulfoniese filmplakkers (PSF) op die skouer, beide bo-op en onder die klere, te plaas, en (iv) om te bepaal wat die persoonlike son-UVR-blootstelling van buitewerkende plaaswerkers op die plaas gedurende die herfs, lente en somer is met die uitvoer van hulle verskeie werksaktiwiteite deur polisulfoniese filmplakkers op hulle arms, bo-op die skouers en bo-op enige kopbedekking te plaas.

Metodes: Die plaas se buite- en binnewerkende werkers het aan die studie deelgeneem. Die plaaswerkers se velkleur en die melanieninhoud van die vel is geklassifiseer deur ’n subjektiewe metode, naamlik vraelyste, asook objektiewe metodes, naamlik die meet van die ITA° en MI. Buitewerkende plaaswerkers se gebruik van okulêre beheermaatreëls is bepaal deur gebruik te maak van ’n vraelys. Die fotobeskerming wat deur die plaaswerkers se klere

gebied word, is gemeet deur ’n PSF-filmplakker op die skouer, onder en bo-op die klere, te plaas en te klassifiseer volgens die vereistes van die AS/NZS 4399:2017-standaard. Die son-UVR-blootstelling van buite- en binnewerkende plaaswerkers is gemeet deur PSF-filmplakkers op die skouer, arm en bo-op die kop te plaas gedurende die herfs, lente en somer tydens verskillende werksaktiwiteite. Werkers se blootstelling is vergelyk met die hoogste waarde van die Internasionale Kommissie van Verligting (CIE) se beroepsblootstellingsdrempel wat 1.3 SED (standaard-eriteemdosis). Etiese goedkeuring vir die studie is verkry vanaf die Noordwes-Universiteit se Gesondheidsnavorsingetiekkomitee (NWU-00101-17-A1).

Resultate: Beduidende verskille is gevind tussen beide die ITA° en MI wat op die konstitutiewe (binnekant van die bo-arm) en fakultatiewe (agterkant van die hand) vel van die plaaswerkers gemeet is. Daar is met behulp van objektiewe metodes vasgestel dat die velkleur van die meerderheid van die plaaswerkers in die Fitzpatrick Fototipe V/Bruin-groep val. ’n Sterk korrelasie is gevind tussen ITA° en MI wat aandui dat beide hierdie objektiewe metodes geskik is om die velkleur van donker gepigmenteerde vel te meet. Die meerderheid buitewerkende plaaswerkers (80%) het nooit sonbrille gedra wanneer hulle buite werk nie. Hoewel meer as 70% van buitewerkende plaaswerkers wel ’n hoed gedra het terwyl hulle werk, het hulle ’n keps verkies eerder as ’n breërandhoed wat beter okulêre beskerming bied. Statisties betekenisvolle verskille is gevind tussen die son-UVR onder en buite die klere wat plaaswerkers gedurende die herfs, lente en somer gedra het. Net 5% van klere het nie die minimumvereiste-fotobeskerming gebied nie. Meer as 75% van die plaaswerkers het gerapporteer dat hulle hul langmoubaadjies op ’n stadium gedurende die dag uittrek, met die gevolg dat hul arms aan die son UVR blootgestel word. Statisties betekenisvolle verskille is gevind tussen die son-UVR wat op die skouer, arm en bo-op die kop gemeet is gedurende die lente en die somer. Die arm ontvang die hoogste blootstelling aan son-UVR blootstelling gedurende die herfs (7.8 SED) terwyl die bokant van die kop die hoogste blootstelling ontvang tydens die lente (11.6 SED) en die somer (13.9 SED). Die son-UVR-blootstelling van alle liggaamsareas het die daaglikse CIE-blootstellingsdrempel oorskry vir meer as 80% van die metings gedurende al drie seisoene.

Gevolgtrekkings: Daar is bepaal dat die velkleur en melanieninhoud van plaaswerkers waarna verwys word in hierdie studie ’n hoë vlak van genetiese fotobeskerming bied. Daar is ook bepaal dat beide die objektiewe en subjektiewe meting van velkleur gebruik kan word om die velkleur van ’n werkgroep te klassifiseer met die doel om die genetiese fotobeskerming van die werkers te bepaal. Die studie het bevind dat die gebruik van okulêre fotobeskermende

maatreëls van buitewerkende plaaswerkers onvoldoende is. Die klere wat die plaaswerkers waarna in die studie verwys word gedra het, het voldoende fotobeskerming gebied, maar die uittrek van die klere gedurende die dag het die beskerming se effektiwiteit verminder. Die blootstelling van buitewerkende plaaswerkers het die voorgestelde CIE-blootstellingsdrempel oorskry, nie net gedurende die somer nie, maar ook gedurende die herfs en lente. Dit dui daarop dat fotobeskermende maatreëls nie net tydens die somer gebruik moet word nie maar ook tydens die ander twee seisoene. Die son-UVR-blootstelling van die buitewerkende plaaswerkers waarna in die studie verwys word, was oor die algemeen hoër as die blootstelling van boere en plaaswerkers in ander lande. Laastens is tien voorstelle aan die makadamianeut- en avokadoplaas gemaak om plaaswerkers se blootstelling aan son-UVR te verminder. ’n Aantal beperkinge van die studie is ook geïdentifiseer en aanbevelings vir verdere studies is gemaak.

Sleutelwoorde: landbou werkers, ultraviolet-stralingberoepsblootstelling, omgewingsgesondheid, velkleur, okulêre fotobeskermende maatreëls, fotobeskermende klere.

PREFACE

This thesis is submitted in article format and written according to the requirements of the North-West University's Manual for Postgraduate Studies and conforms to the requirements preferred by the appropriate journals. The thesis is written according to United Kingdom English spelling, with the exception of institutional names and references that were used as is. The following four articles are included in this thesis:

Article I: Subjective and objective skin colour of a farmworker group in the Limpopo Province, South Africa

Article II: Low use of ocular sun protection among agricultural workers in South Africa: Need for further research

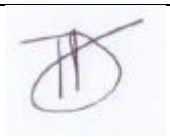
Article III: Ultraviolet radiation protection factor of clothing: South African farmworkers on a macadamia nut and avocado farm

Article IV: Personal solar ultraviolet radiation exposure of farmworkers: seasonal and anatomical differences suggest prevention measures are required.

For uniformity, the reference style required by the journal *Annals of Work Exposures and Health* is used the most in the thesis. The author instructions for this journal are located in the beginning of Chapter 5 and 6. The exceptions are Chapter 3 and Chapter 4 which are written according to the guidelines of the journals, *Skin Research and Technology* and *Photochemistry and Photobiology,* respectively. Details on the requirements of reference styles can be found in the beginning of Chapters 4, 5 and 6 of this thesis.

The contributions of the listed co-authors and their consent for use in this thesis are given in Table 1. The relevant editors or publishers granted permission for the use of the published material.

Table 1: Contributions of various authors and consent for use

Author	Contribution to the thesis	Consent*
Ms K. Linde	Responsible for the planning of the study design, completion of ethics application, and the data collection. Responsible for data collection by performing personal solar UVR exposure monitoring, skin bioengineering measurement and photoprotective usage studies at the macadamia nut and avocado farm. Responsible for data analysis and interpretation of the results. First author of the manuscripts/articles included in Chapters 3 – 6. Responsible for writing the thesis.	
Prof J.L. du Plessis	As Promoter, supervised the design and planning of the study, obtaining ethics approval for the study, and supervised the data collection and the writing of the thesis. Provided intellectual input on statistical analysis, interpretation of data and the writing of articles and the thesis.	
Prof C.Y. Wright	As Co-promoter, supervised the design and planning of the study and the data collection and the writing of the thesis. Provided intellectual input on statistical analysis, interpretation of data and the writing of articles and the thesis.	
Ms T. Kapwata	Responsible for map used in articles included in Chapter 3 and Chapter 6 Responsible for data analysis in article included in Chapter 4.	

* I declare that I have approved the chapter/article(s) and that my role in the study as indicated above is representative of my actual contribution, and that I hereby give my consent that it may be published as part of the PhD thesis of Ms K. Linde.

The outline of the thesis is as follows:

- Chapter 1 - General introduction with background research aims and objectives, and hypotheses
- Chapter 2 - A literature study on topics relevant to this thesis
- Chapter 3 - Article I entitled: Subjective and objective skin colour of a farmworker group in the Limpopo Province, South Africa, published in *Skin Research and Technology*
- Chapter 4 - Article II: Low use of ocular sun protection among agricultural workers in South Africa: Need for further research, submitted to *Photochemistry and Photobiology* to be considered for publication
- Chapter 5 - Article III: Ultraviolet radiation protection factor of clothing: South African farmworkers on a macadamia nut and avocado farm, submitted for publication to *Annals of Work Exposure and Health* to be considered for publication
- Chapter 6 – Article IV: Personal solar ultraviolet radiation exposure of farmworkers: Seasonal and anatomical differences suggest prevention measures are required, submitted for publication to *Annals of Work Exposure and Health*
- Chapter 7 – A summary of the main findings of the study is provided and conclusions are drawn. Additionally, recommendations are made and the limitations of the study as well as recommendations for future studies are provided.
- Appendix A: Ethics approval certificate
- Appendix B: Proof of submission of articles II, III and IV to scientific journals
- Appendix C: Declaration of language editing
- Appendix D: Questionnaires

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LIST OF ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
ANOVA	Analysis of variance
AS/NZS	Australia/New Zealand Standard
CANSA	The Cancer Association of South Africa
CEN	European Committee for Standardization
CIE	International Commission of Illumination
DNA	Deoxyribonucleic acid
FST	Fitzpatrick skin phototype
ICNIRP	International Committee for Non-Ionizing Radiation
IRPA	International Radiation Protection Association
ITA°	Individual typology angle
MI	Melanin index
PSF	Polysulphone
STATS SA	Statistics South Africa
sUVR	Solar ultraviolet radiation
USA	United States of America
UVI	Ultraviolet index
UVR	Ultraviolet radiation
UPF	Ultraviolet radiation protective factor

LIST OF UNITS

%	percentage
≤	less or equal to
<	less than
>	greater than
±	plus-minus
mg	milligram
n	number
nm	nanometer
®	registered trademark
SED	standard erythemal dose

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CHAPTER 1: GENERAL INTRODUCTION

1.1. Introduction

Approximately 5.39% of the formal South African workforce in the fourth quarter of 2019 was involved in agricultural activities as part of their daily lives with still more individuals forming part of the informal agricultural sector (STATSSA, 2020). A significant number of agricultural activities that are carried out by the agricultural workforce takes place in the outdoor environment where solar ultraviolet radiation (UVR) is present (ICNIRP, 2010; Nardini *et al.*, 2014a). These activities may include preparation of soil, planting, pruning of vineyards and fruit trees, fertilization fields and harvesting crops (Schmalwieser *et al*., 2010; Siani *et al*., 2011). The specific agricultural activities are determined by the type of crop produced or livestock raised on the farm (Siani *et al*., 2011). A wide variety of different types of crops that are commonly found on farms in South Africa which include maize, wheat, cattle, sheep, chickens and a variety of fruits (WWF, 2010).

Outdoor workers are generally regarded as being at high risk of overexposure to solar UVR while indoor workers are classified as a low risk group (ICNRIP, 2010). Although the exposure of outdoor to solar UVR during their leisure time did not differ from that of indoor workers, outdoor workers were exposed to significantly higher solar UVR levels during their work (Grandahl *et al*., 2018). This higher solar UVR exposure of outdoor workers was also linked to an increased risk of developing skin cancer as shown by the EPIDERM study, a large case-control study that included patients diagnosed with skin cancer from a number of European countries (Trakatelli *et al*., 2016).

Numerous health effects, both positive and negative, are related to solar UVR exposure. Positive health effects are related to the synthesis of Vitamin D and its associated roles in the body including bone mineralisation and its possible protective role against diseases such as Parkinson's disease and treatment of skin conditions such as lupus vulgaris and schlerosing skin conditions (Feister *et al*., 2011, Juzeniene and Moan, 2012; Gatto *et al*., 2015; Gunton *et al*., 2015). In contrast, the negative health effects include melanoma (CMM) and non-melanoma skin cancers (NMSC) (also known as keratinocytes cancers), immunosuppression and ocular diseases (e.g. pterygium and cataracts) (Yam and Kwok, 2014; Greinert *et al*., 2015). In light of the abovementioned positive and negative health effects, care should be taken to balance the necessity of a minimum level of solar UVR exposure and the risk of excessive exposure (Kimlin *et al*., 2016).

Statistics show that UVR-related cancers such as skin cancers, both CMM and NMSC, affect a substantial part of the population in South Africa. This prevalence is illustrated by the number of these cancers histologically diagnosed during 2014. Specifically, approximately 39% of cancers diagnosed in males and approximately 28% diagnosed in females were identified as skin cancers (NCR, 2019). Additionally, the occurrence of NMSCs has been found to be higher in HIV positive individuals than the general population which may indicate an increased risk for the South African population as approximately 13.5% of the population is HIV positive (Silverberg *et al*., 2013; STATS SA, 2019).

Genetic variations between individuals play a role in determining the extent of both the above mentioned positive and negative health effects by influencing an individual's skin response to solar UVR exposure (Swalwell *et al*., 2012; Al-Jamal *et al*., 2014). Skin colour and the magnitude in the change in skin colour due to exposure to UVR are examples of this effect of genetic variations (Brenner and Hearing, 2008; Shin *et al*., 2014). South Africa has a population of which 80.7% are classified as Black African, 8.8% as Coloured, 2.6% as Indian or Asian and 7.9% as White (STATS SA, 2019). This unique genetic diversity provides a challenge in predicting the effect that exposure to a specific level of UVR will have on a group of individuals, especially a group that is as diverse as those routinely found in the South African work force.

An increase in melanin content as well as a thickening of the stratum corneum of the skin's epithelium is a result of exposure to solar UVR. The increase in the production of melanin in the skin by melanosomes is possibly a reaction to prevent damage to DNA in the cells caused by solar UVR. Melanin plays a role in protection against UVR reaching the inner structures of the body by scattering or absorbing solar UVR. The thickening of the stratum corneum of the epithelium also contributes to body's protective efforts against solar UVR. However, this measure is not as effective as an increase in pigmentation of the skin due to increased melanin content (Brenner and Hearing, 2008). The initial level of melanin in an individual's constitutive or skin shielded from exposure to solar UVR is determined by genetics (Yamaguchi *et al.*, 2007). Additionally, the individual's genetic makeup determines the degree of increase in melanin or pigmentation of their facultative or solar UVR exposed skin (Ravnbak, 2010). These differences in the colour between both the constitutive (skin protected from solar UVR exposure) and facultative skin (skin exposed to solar UVR) of individuals have been used to formulate a subjective skin phototype classification system by Fitzpatrick which was expanded to include classification of both light coloured and dark coloured individuals (Fitzpatrick,1988; Brenner and Hearing, 2008). Objective methods have also been developed to classify skin

colour using spectrometry such as individual typology angle (ITA°) and melanin content (Eilers *et al*., 2013). Although individuals classified as possessing a skin phototype that provides a high level of protection against solar UVR, skin damage may still occur if exposure to solar UVR is high enough (Fitzpatrick, 1988; Al-Jamal *et al*., 2014). There is a lack of knowledge regarding both the constitutive skin colour of farmworkers and the precise changes that occur to the facultative skin of South African outdoor farmworkers after exposure to occupational solar UVR. These changes may be determined by factors that are unique to the South African agricultural sectors.

Behavioural factors such as the type of work activity performed by the individual or the use of photoprotective measures, including protective clothing and measures used to protect the eyes (such as the wearing of hats and sunglasses), is a contributing factor to the solar UVR exposure of workers (Jansen *et al*., 2013). The main purpose of photoprotective measures is to provide protection in addition to an individual's genetic photoprotection in order to either prevent or reduce their exposure to solar UVR (Al-Jamal *et al*., 2014). The protection provided by clothing to solar UVR is dependent of factors such as the age and the thickness of the material that the clothing consists of. Protective clothing also includes items such as hats and sunglasses (Jansen *et al*., 2013). The evaluation of the use of specific photoprotective measures such as ocular photoprotective measures and protective clothing will provide a more comprehensive view of the risk posed to the diverse types of individuals working in the broader Limpopo agricultural sector.

A recommended solar UVR exposure standard of 30 J/m^2 or 0.3 standard erythemal dose (SED, 1 SED = 100 J/m^2) for eight hours has been set using the American Conference of Governmental Industrial Hygienists (ACGIH) action spectrum with an equivalent exposure limit of 109 J/m^2 or 1.09 SED or a range of 1.0 to 1.3 SED using the International Commission of Illumination (CIE) action spectrum (Moehrle *et al*., 2003; ICNIRP, 2010). However, the first exposure standard as used by ACGIH, the International Committee for Non-Ionizing Radiation (ICNIRP) and the International Radiation Protection Association (IRPA) has been criticised as only a short period of exposure to solar UVR is needed to exceed the standard; the standard was also developed using artificial UVR and the application of the standard to all individuals irrespective of the photoprotection provided by their skin phototype (Milon *et al*., 2007). Alternatively, a range of 1.0 to 1.3 SED is also used on the CIE action spectrum as an exposure limit (EN14255-3). Although there is no statutory standard for occupational solar UVR exposure in South Africa at this point in time, the legislation governing occupational exposure to environmental stressors require employers to protect the health and safety of employees

(South Africa, 1993; South Africa, 1996). A lack of knowledge regarding the level of solar UVR exposure of workers in specific South African workplaces and its compliance with recommended exposure controls, prevents the efficient protection of those individuals due to the inability to implement the most appropriate control measures for the specific work scenarios.

In Poland, Spain, Austria, Canada and New Zealand it has been found that outdoor workers, including agricultural, landscaping and horticultural workers are exposed to solar UVR at levels that exceeded the recommended exposure limits which may lead to the already mentioned negative health effects (Hammond *et al*., 2009; Bodekær *et al*., 2015; Peters et al., 2019). The general risk posed to outdoor workers of receiving excess solar UVR exposure in various regions of South Africa have been estimated by Wright *et al*. (2013) using ambient UVR measurements. The researchers acknowledged that personal UVR exposure measurements would provide more detailed information regarding individual exposures, as well as the existence of a lack of knowledge regarding the attitudes and practices amongst South African outdoor workers. A case study conducted in Pretoria using a handheld ultraviolet index (UVI) meter to record the personal exposure of an outdoor worker found that the outdoor worker was exposed to 84% of the ambient solar UVR resulting in a risk of exposure to UVR at a harmful level (Makgabutlane and Wright, 2015). A study by Nkogatse et al. (2019) also found that different body sites of South African open parking security staff received solar UVR levels that exceeded the recommended exposure limit.

The level of solar UVR exposure, as well as the risk posed, is determined by environmental influences such as the latitude, altitude and specific terrain of the area. For example, geographic areas closer to the equator have been found to have higher ambient solar UVR levels while rocky terrain reflect higher levels of solar UVR than grassy areas. Due to these various environmental influences, it would not be possible to predict the level of exposure in a country by referencing exposures of similar outdoor workers in other countries (González *et al*. 2008; Corrêa, 2015). The levels of solar UVR that outdoor farmworkers are exposed to in the Limpopo Province has not yet been determined through the measurement of personal UVR exposure or any estimation made of behaviour regarding solar UVR protective measures. This is a significant gap in knowledge as the Limpopo Province is the province located the closest to the equator.

This thesis aims to evaluate the subjective and objective skin colour of a group of farmworkers on a macadamia nut and avocado farm in the Limpopo Province of South Africa in order to

classify the natural photoprotection of the farmworkers and determine the both the colour changes and melanin content of skin exposed to solar UVR. The occupational exposure of these farmworkers to solar UVR and the photoprotective measures, in particular ocular protection, that they use will also be assessed. These finding in conjunction with the evaluation of the UVR protection provided by the clothes they wear, will give a more comprehensive representation of potential risk posed to the health of these outdoor farmworkers and the required control measures that should be implemented to safe guard both their acute and chronic health and wellbeing.

1.2. Research aims and objectives

1.2.1. General aim

The general aim of this thesis is to quantify the differences in skin colour and melanin content of facultative and constitutive skin of farmworkers on a macadamia nut and avocado farm in the Limpopo Province of South Africa, as well assessing the existing photoprotective control measures and practices of those farmworkers together with their occupational exposure to solar UVR to determine if the exposure poses a risk to their health.

1.2.2. Specific objectives

The specific objectives of this thesis are:

i. To compare the differences in skin colour (ITA°) and melanin content between the facultative and constitutive skin of farmworkers working on a macadamia nut and avocado farm in the Limpopo Province of South Africa using skin bioengineering measurements.

ii. To assess the solar UVR practices, in particular the use of ocular protective measures, of South African macadamia nut and avocado commercial farmworkers in their workplace using questionnaires.

iii. To determine the photoprotection provided by the clothing worn by farmworkers using polysulphone badges on the shoulder both under and on top of the clothing worn by the farmworkers.

iv. To assess the personal solar UVR exposure of outdoor farmworkers during autumn, spring and summer while carrying out their different work activities of a group of farmworkers on a macadamia nut and avocado farm in the Limpopo Province of South Africa through polysulphone badges placed on their arms, top of the shoulder and top of any head covering worn.

1.3. Hypotheses

The following hypotheses are postulated:

I. Differences in the pigmentation between sun exposed (facultative) skin and constitutive skin has been found in some skin phototypes (Choe *et al*., 2006). It is hypothesised that there is a significant difference in objectively measured ITA° and melanin index (MI) between the constitutive and facultative skin of farmworkers on a macadamia nut and avocado farm in the Limpopo Province of South Africa.

II. The use of photoprotective measures by agricultural workers such as farmers have been found to be infrequent (Kearney *et al*., 2014). Specific photoprotective measures that focus on protecting the eyes such as wearing sunscreen and sunglasses while working in the sun was also found to be used by less than 35% and 20% of farmers in Germany, respectively (Schneider *et al*., 2018). It is hypothesised that the ocular protection practices, such as wearing hats and sunglasses, of a group of South African commercial farmworkers on a macadamia nut and avocado farm in the Limpopo Province while working in the sun is infrequent (corresponding to other similar published studies).

III. The personal solar UVR exposure of farm and horticultural outdoor workers in Poland, Spain, Austria and New Zealand exceeded the CIE exposure limit over eight hours (Hammond *et al*., 2009; Bodekær *et al*., 2015). However, Nardini *et al*. (2014b) found that Italian commercial farmworkers were exposed to a higher personal UVR level during summer than winter with only solar UVR exposure during summer exceeding the CIE exposure limit. Wright *et al*. (2011) also found that UV-related health risks were posed to outdoor workers in a number of South Africa area not only during summer but also to a lesser extent during autumn and spring through the use of area monitoring. Therefore, it is hypothesised that the personal UVR exposure of a group of South African outdoor farmworkers on a macadamia nut and avocado farm

exceeds the highest level of the range CIE exposure limit of 1.3 SED/8 hours during autumn, spring and summer.

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CHAPTER 2: LITERATURE STUDY

This chapter critically addresses literature relevant to the content of this thesis. The discussion first addresses the South African agricultural sector, the physical characteristics of ultraviolet radiation (UVR), the positive and negative health effects associated with exposure to solar UVR, as well as the influence of an individual's genetics on the health effects. This is followed by an overview of the influence of environmental and behavioural factors on personal UVR exposure and the occupational solar UVR exposure of outdoor workers is also examined. Finally, the solar UVR occupational exposure limits and the risk posed by the UVR exposure to outdoor workers in South Africa are discussed.

2.1. The South African outdoor labour sector

The formal employment sector in South Africa can be subdivided into several industries, including mining, agriculture, transport, finance, construction and utilities, where significant percentages of individuals are employed (STATSSA, 2020). Of these industries, there are a number of occupations that include activities where workers work predominantly outdoors in the sun, such as agriculture and construction (ICNIRP, 2010; STATSSA, 2020). Although mining is not included in the list of industries that have a high risk of exposure to solar UVR by organisations such as ICNIRP (2010), workers in the mining sector, especially at open pit mines, may still be in danger of excessive exposure (DNRME, 2010).

During the fourth quarter of 2019, approximately 5% of the formal Southern African work force was employed in the agricultural sector (STATSSA, 2020). In spite of this relatively large percentage of the formal South African work force involved in this sector, there are additional types of agriculture found in South Africa other than commercial farming (STATSSA, 2016; Kong *et al*., 2014). Smallholder farms produce crops for both own use and to sell. However, the production levels tend to fluctuate which may result in the farm produce sufficient as surplus crop to sell to transition into a commercial farm. That same variation may result in the production of only enough crops to fulfil the family's own use resulting in the reclassification as a subsistence farm (Kong *et al*., 2014). The majority of agricultural activity results in a large amount of work that requires outdoor activity in the sun which contains UVR (Siani *et al*., 2011).

Construction work includes activities such as erection, renovation, conversion work and demolition of structures such as buildings or bridges as well as the clearing of land (South

Africa, 2003). The type of activities that workers carry out while working on construction sites mostly require frequent movement and variety in the specific activity done by a specific worker (Milon *et al*., 2007).

Open-pit mining or open-cut mining and underground mining are defined by Whittle *et al*. (2018) as “an open excavation from the surface” and “a network of tunnels and/or shafts giving access to the minerals underground”, respectively. One mining operation does not necessarily function exclusively as one type of mine for its entire life span with some converting from an open-pit to underground mine (Whittle *et al*., 2018). The percentage of workers in South Africa employed in the mining sector is approximately 2% according to the first Quarterly Labour Force Survey of 2020. However, no distinction is made between workers at an open-pit mine or an underground mine (STATSSA, 2020).

2.2. Physical characteristics of ultraviolet radiation

The sun and associated solar radiation is a constant feature in everyday life. All regions of the electromagnetic spectrum are emitted as part of solar radiation including optical radiation which consists of ultraviolet radiation (UVR), visible light and infrared radiation (ICNIRP, 2007). Similar to the grouping of the different regions of the electromagnetic spectrum according to wavelength, the UVR region has been subdivided into UVA, UVB and UVC (ICNIRP, 2010). Although the wavelength boundaries of the three sub-regions namely UVA (315-400 nm), UVB (280-315 nm) and UVC (100-280 nm) was already recommended in 1932 at the Second International Congress on Light, over time certain disciplines have used different boundaries specifically for UVB (Diffey, 2002). An example of this deviation is the wavelength range of 290-320 nm often used by environmental and dermatological photobiologists which in part led to a joint technical report by the Commission International de L’Eclairage (CIE) and the World Meteorological Organization (WMO) to standardise the range as 280-315 nm (Diffey, 2002; CIE, 2014). The standardization was necessary to prevent significant discrepancies in UVB values due to the use of the different boundaries (CIE, 2014).

Although all three UVR regions are found in solar radiation, only the UVA and UVB bands of soıar UVR reaches the surface of the earth (Greinert *et al.*, 2015). The only terrestrial means of exposure to UVC is through artificial sources such as welding (ICNIRP, 2010). This phenomenon is due to the complete absorption of solar radiation of the UVC wavelengths by primarily ozone gas that is present in the atmosphere. In addition, a large portion, although not all, of UVB radiation is absorbed in the same way with a small portion of UVA radiation

absorbed (Corrêa, 2015). As UVA and UVB are the regions or bands of solar UVR that individuals come into contact with the most, it is the positive and negative health effects caused by these two types of solar UVR that is of importance.

2.3. Health effects associated with solar UVR exposure

Exposure to solar UVR is both necessary to the physiological process of forming vitamin D in the human body, as well as a risk factor for developing negative health effects such as skin cancer (Kimlin *et al*., 2016).

2.3.1. The role of the different UVR regions on the development of health effects

Exposure to UVB leads to different types of negative health effects than exposure to UVA. The type of health effect that is linked to either UVA or UVB is determined by the specific layer of skin that absorbs that type of UVR. This relationship is shown by the prominence of UVB associated health effects found in the epidermis, which almost completely absorbs the specific region of UVR, compared with the UVA associated health effects found deeper in the dermis which comes into contact with approximately 30-50% of the UVR region (Reichrath, 2007).

2.3.2. Positive health effects

Exposure to solar UVR has been found to be necessary for the body to produce vitamin D which is needed for effective bone mineralisation and musculoskeletal health (Gunton *et al*., 2015; Pierot-Deseilligny and Souberbielle, 2017). The presence of vitamin D has also been linked to lowering the risk of developing certain neurological conditions and internal cancers (Adams *et al*., 2016; Pierrot-Deseilligny and Souberbielle, 2017). Although most of the positive health effects associated with exposure to UVR have been linked to vitamin D, there are some that have been linked to other mechanisms such as the production of β-opioids (Fell *et al*., 2014).

2.3.2.1. Vitamin D related positive health effects

Exposure to UVR is the most efficient vitamin D source naturally available to individuals and it is the source of approximately 90% of vitamin D that is required by the body (Reichrath, 2007; Kimlin *et al*., 2016). The UVR that comes into contact with the skin, converts 7-dehydrocholesterol found in the skin to vitamin D. Subsequently, the synthesised vitamin D is first hydroxylated to 25-hydroxyvitamin D and finally to 1,25-dehydroxyvitamin D which is the main active form of vitamin D. Although 1,25-dehydroxyvitmain D is the active form, the form that is measured to determine an individual's vitamin D status is 25-dehydroxyvitamin D

(Gunton *et al*., 2015). Currently, the optimum serum concentration of vitamin D ranges between 30 to 60 mg/ml or 75 to 150 mmol/l (Pierrot-Deseillingny *et al*., 2017).

Maintaining the level of 1,25-dehydroxyvitamin D that is circulated in the blood above the lower limit is crucial as this activated form of vitamin D is involved in a number of physiological processes such as the mineralisation of bones and musculoskeletal health as shown by muscle weakness that develops with vitamin D deficiency (Gunton *et al*. 2015; Pierrot-Deseillingny and Souberbielle*,* 2017). Vitamin D is integral in the active absorption of calcium from the gastrointestinal tract. The relationship between vitamin D and both bone and muscle health is indicated by the prominence of fractures of weakened bones due to falls caused by muscle weakness in vitamin D deficient patients (Gunton *et al*. 2015).

In addition to the development of osteomalacia in adults with insufficient vitamin D levels, studies have also found indications that vitamin D deficiency is present in individuals suffering from Parkinson's disease in patients under 70 years, Alzheimer's disease and older-onset rheumatoid arthritis. These findings imply that vitamin D acts as a protective molecule against these diseases (Sloka *et al*., 2008; Arkema *et al*., 2013; Laczmański *et al*., 2015; Kravietz *et al*., 2017). Exposure to solar UVR has also been found to decrease the risk of developing multiple sclerosis, particularly early onset multiple sclerosis, potentially due to the consequent increased levels of Vitamin D or solar UVR's immunosuppressive qualities (Gallagher *et al*, 2019).

Furthermore, there are indications of inverse correlations between vitamin D levels in the body and the risk of cancers such as prostate cancer, breast cancer as well as oral, pharyngeal and cervical cancer (Bodiwala *et al*., 2003; Adams *et al*., 2016; Grant 2017). However, these negative correlations have been disclaimed by Zamoiski *et al.* (2016) in the case of breast cancer, Peters *et al*. (2016a) in the case of prostate cancer and Godar *et al.* (2014) in the case of oral, pharyngeal and cervical cancer. The reason for these contradictory findings include differences in the methodology of these studies, for example Zamoiski et al. (2016) used questionnaires to collect self-reported data while Grant (2017) used ecological studies to investigate the link between vitamin D levels and incidence of breast cancer.

2.3.2.2. Non-vitamin D related positive health effects

Other positive health effects due to exposure to UVR that is not related to vitamin D have also been identified. Phototherapy consists of using solar UVR to treat diseases such as atopic dermatitis and the various diseases that are classified as sclerosing skin conditions (Juzeniene

and Moan, 2012). An example of a sclerosing skin condition that may be successfully treated with phototherapy is scleredema adultorum (Yoshimura *et al*., 2014). Yoshimura *et al*. (2014) found that treatment with narrow band UVB produced faster positive results than treatment with UVA. Mechanisms through which the UVA and UVB bands of UVR treat these diseases include immunosuppression in both the epidermis and dermis of the skin (Juzeniene and Moan, 2012).

Exposure to UVR has also been linked to increased levels of β-endorphin, which is an opioid associated with mood enhancement, in the body (Juzeniene and Moan, 2012). Researchers have reported conflicting findings regarding UVR's involvement in the production of β-endorphin, with study findings both supporting and disputing this link (Wintzen *et al*., 2001; Fell *et al*., 2014). However, it should be noted that the two studies that confirmed this link, namely Fell *et al*. (2014) and Jussila *et al*. (2016), focused on UVB exposure while the study, Wintzen et al. (2001), that disputes the link focused on UVA, which may have contributed to the different findings.

2.3.3. Negative health effects

The correlation between a number of negative health effects and exposure to UVR has been identified and studied. Negative health effects may range from erythema to the development of different types of cancers and photoaging. The skin and eyes are the organs of the body that are most often negatively affected as they are directly exposed to the UVR. However, some systemic negative health effects have been observed such as the immunosuppression (Walterscheid *et al*., 2006; Norval *et al.*, 2007).

2.3.3.1. Melanoma skin cancer

Cutaneous malignant melanoma (CMM) is a skin cancer, which if developed, results in death more regularly than other skin cancers. This skin cancer is associated with epidermal melanocytes and pre-existing moles or nevi (D'Orazio *et al*., 2013). In most cases CMM manifests as a dark coloured macule which may have grown in size in a short period of time (Agbai *et al.*, 2014). Several mechanisms are proposed to be involved in the development of CMM with the decrease in signalling MC1R alleles as an example. As MC1R signalling is involved in prevention of damage to the skin caused by UVR, the loss of these alleles would negatively impact the body's natural photoprotection (D'Orazio *et al*., 2013). Another mechanism related specifically to UVB exposure, put forward by Tyagi *et al*. (2015), includes the activation of cellular tumour-promoting signalling pathways and increased deleterious mutations in human epidermal keratinocyte cells (Tyagi et al., 2015). Family predisposition

may also play a part in approximately a tenth of CMM cases. In these cases, mutations mostly in the CDKN 2A gene and, to a lesser degree, the CDK 4 gene of germ cells have been observed (Green *et al*., 2011).

Four major types of CMM have been identified according to histological features (Bradford *et al*., 2009). The mechanisms which by the different types develop are also different (Norval and Wright, 2017). The first type is called a superficial spreading melanoma (SMM) which is the most common subtype in individuals with light skin. The second type of CMM is called a nodular melanoma (NM) which has a phase of vertical growth. The third type is called a lentigo maligna melanoma (LMM) which is related to chronic exposure to solar UVR in those older individuals with light skin on sun exposed body sites. The fourth type of CMM is named an acryl lentiginous melanoma (ALM) which is the most common CMM found in individuals with dark skin, such as those of African or Asian descent (Bradford *et al*., 2009; Mahendraraj *et al*., 2017; Diepgen, 2020). An ALM can be defined as 'pigmented legions on the extremities, particularly on plantar regions such as the palms of the hands and soles of the feet, which are characterised by a lentiginous (radial) growth phase evolving over months or years to a dermal (vertical) invasive stage' (Fernandez-Flores and Cassarino, 2017). Although exposure to solar UVR is considered a risk factor for CM, the link between solar UVR exposure and all types of CM is disputed. Numerous epidemiological and genetic research studies have found that there is no link between solar UVR exposure and ALM. This contributed to the view that mechanisms for the development of CM involving solar UVR are less important with regard to individuals with dark skin that other mechanisms (Liu *et al*., 2016; Norval and Wright, 2017; Wright *et al*., 2020). Additionally, the variation of the UVR exposure that would lead to an increased risk of any type of CMM, namely chronic, intermittent or total exposure has also been disputed (Belbasis *et al*., 2016).

Although CMM is regarded as the most malignant skin cancer, the incidence of this cancer is lower than other skin cancers in South Africa as shown by the National Cancer Registry (NCR) statistics for cancers histologically diagnosed in 2016. The incidence of melanoma in both females and males diagnosed was lower when compared to keratinocyte cancers (KC) with CMM incidence for all females and all males at 2.25% and 2.92%, respectively. This trend was observed in all groups classified by both population group and gender with 4.37% of cancers in White males as the highest incidence in South African males and 0.92% of Black males the lowest incident of CMM. White females were also the female population group that was diagnosed with CMM most often (4.13%) while Black females was the female group fewest CMM diagnoses (0.88%) (NCR, 2020). In addition, data from 2000 to 2004 showed that the

mean age-standardized incidence per 100 000 in White South African males was 198 for BCC and 70 for SCC while in White South African females, it was 113 for BCC and 32 for SCC. These values are much higher than the incidence in Black South African males which was 3.0 for both BCC and SCC and Black South African females which was 1.7 for BCC and 1.6 for SCC (Wright *et al*., 2020).

Early detection is paramount in the treatment of CMM as surgical removal treatment is only effective in the earlier stages (Richtig *et al*., 2008; D'Orazio *et al*., 2013). The importance of early diagnosis is also indicated by the lower survival rate in individuals with deeply-pigmented skin with CMM, with diagnoses typically occurring later and when the CMM is more advanced. The location of CMM tumours in these populations also tends to be on an individual's extremities which would classify it as an ALM (Agbai *et al*., 2014). Between 2002 and 2004, 69% of CMM in Black African males in South Africa were located on their lower limbs or hips while the most common location on White males in South Africa was found on their trunk (37%). The percentage of CMM found on the lower limbs or hips of Black African females for the same time period is even higher at 72%. Similarly, the percentage of CMM found on the limbs and hips of White females are also higher (41%) than when compared to the percentage in White males (Noval and Wright, 2017).

2.3.3.2. Keratinocyte cancers

The term non-melanoma skin cancer (NMSC) is also used as an umbrella term under which BCC and SCC falls. However, the argument has been made that the use of the term KCs is more accurate as it refers to the link with keratinocytes shared by BCC and SCC (Karimkhani *et al*., 2015). Although the prognosis when developing KCs is not normally fatal, the tumours may be disfiguring and influence an individual's quality of life (Ahmed *et al*., 2008).

Statistics from the NCR related to cancers diagnosed histologically in 2016 in South Africa shows that BCC was the second most commonly diagnosed cancer in males and third most common in females (21.15% and 14.45%, respectively) while SCC was the fourth most commonly diagnosed cancer in females at 6.32% and the third most common in males at 10.95%. The most commonly diagnosed cancer in both White males and females was BCC at 31.91% and 35.4%, respectively. The lowest incidence of diagnoses of BCC was found in Black African females with 1.65% but the lowest percentage of cancers diagnosed as SCC was found in the Asian female group (1.21%) (NCR, 2020).

A number of major pathways are involved in the pathogenesis of the two skin cancers that are often referred to as the collective term keratinocytes cancers. In one of these major pathways, UVR inactivates the TP53 gene by inducing mutations in the gene. The gene has a tumour suppression role which, if not carried out, results in the uncontrolled proliferation of precancerous keratinocytes (Madan *et al*., 2010). The two types of tumours have different origins with SCC developing from epidermal keratinocytes, while BCC develops from basal germinative cells (Ahmed *et al*., 2008). Actinic keratosis is also seen as a frequent sign of the future development of SCCs (Agbai *et al*., 2014). In addition, development of SCC has been linked to chronic solar UVR exposure while the development of BCC is linked to exposure to intensive and intermittent solar sUVR exposure (Diepgen *et al*., 2020). There is also a difference in their physical appearance. The classic BCC is an ulcer with an edge that is hardened (indurated), while the middle presents the disintegrated tissue associated with an ulcer. Often the carcinoma also has a pearly or waxy appearance with small dilated blood vessels visible (Madan *et al.*, 2010). Additionally, other BCC subtypes are found such as nodular, morphoeic, cystic, superficial (multicentre) and pigmented (Diepgen et al., 2020). In contrast, a SCC's appearance can be described as a papule, which is a solid, round elevation of the skin, or plague which is superficial and has a raised base (Agbai *et al*., 2014).

The locations on the body where KCs are commonly found differ according to the melanin content of the skin. This is illustrated by the conclusion that SCCs are most commonly found on the lower extremities of people with dark skin, such as the feet and legs while in people with light skin this type of carcinoma is most commonly found in the areas of the skin that is most exposed to the sun (Agbai *et al*., 2014). The diagnoses of BCCs is also more challenging in people with darker skin as in people with lighter skin due to increased pigmentation in the carcinoma which makes it difficult to distinguish between the skin itself and the carcinoma (Gupta *et al*., 2016). This challenging diagnosis has led to misdiagnoses of KCs as shown by the case studies presented by Newsome and Subash (2017). Examples of these case studies include the misdiagnoses of a KC on the genitals of a middle aged Black male as herpes as well as the misdiagnoses of a growth under the finger nail of the Black female in her thirties as a hang nail. These misdiagnoses were only corrected after the patients had undergone the incorrect treatment for years (Newsome and Subash, 2017).

2.3.3.3. Ocular diseases

Although there are natural reflexes that protect the eyes from exposure to UVR such as the dislike of looking into direct sunlight, as well as anatomical protection such as brows shielding the eyes from sun, a number of ocular diseases are still linked to especially indirect UVR

exposure (Norval *et al*., 2007). As in the case of skin, the effect of UVR on the eyes is also dependent on the structure of the eye that absorbs the radiation (Ivanov *et al*., 2018). The absorbing structure is determined by the wavelength of the electromagnetic radiation with the shorter wavelengths absorbed by the cornea, while longer wavelengths are more likely to be absorbed by the deeper structures such as the lens (Saccà *et al*., 2013; Yam and Kwok, 2014). Ocular diseases linked to UVR exposure include eyelid KCs, pterygium and cortical cataracts (Ivanov *et al*, 2018).

Both BCC and SCC of the eyelid are associated with UVR exposure, although the association is more prominent for SCC (Yam and Kwok, 2014). Intracellular damage is caused by UVR through mechanisms that include the increased formation of reactive oxygen species (ROS). This intercellular damage may result in hyperplasia of the bulbar conjunctiva which is called pterygium. Hyperplasia or the increase in the number of cells in the tissue of the bulbar conjunctiva, results in the growth of the structure to such an extent that the conjunctiva covers the cornea (Norval *et al*., 2007; Saccà et al., 2013; Yam and Kwok, 2014). Pterygium has been specifically linked to chronic UVB exposure (Ivanov *et al*., 2018). There is a positive correlation between the development of cataracts, or the opacification of the crystalline lens, and exposure to a high level of ambient UVR (Delcourt *et al*., 2014; Yam and Kwok, 2014). The polysaccharides, crystalline proteins and lipids in the lens are damaged by an increase in ROS and hydrogen peroxide caused by UVR which leads to the development of cataracts (Ivanov *et al*., 2018).

2.3.3.4. Immunosuppression

Both the UVA and UVB regions of solar UVR suppress the immune system of exposed individuals using mechanisms that are unique to each region. Exposure to UVR leads to immunosuppression both in the skin and on a systemic level such as the reactivation of latent *Herpes simplex* virus infections (Bernard *et al*., 2019). The mechanisms involved in immunosuppression in the skin by UVA include oxidative stress caused by ROS and reactive nitrogen species which affect macromolecules such as proteins and DNA (Halliday *et al*., 2012; Greinert *et al*., 2015). In contrast, UVB affects the immune system through immunosuppressive mediators as well as increased suppressor cell creation and disturbing the work of effector and memory T-cells (Greinert *et al*., 2015). Factors such as gender and skin melanin content also determine the level of immunosuppression. The effect of gender is illustrated with research findings where men experienced a higher degree of immunosuppression than women after being exposed to the same UVR dose. Decreased skin melanin content results in a higher risk of immunosuppression (Damian *et al*, 2008).

Suppression of the immune system due to exposure to solar UVR has also been linked to an increase risk of developing KC (Damiani and Ullrich, 2016). The incidence of BCC and SCC has been found to be higher in individuals that are infected with the human immunodeficiency virus (HIV) (Silverberg *et al*., 2013). In a South African context, York *et al*. (2017) found that HIV infection may have contributed to the high incidence of SCC found in a retrospective chart review of skin cancers. The incidences of melanoma, SCC and BCC in organ transplant recipients are significantly higher than in the individuals who have not undergone the procedure (Athar *et al*., 2011). Prior exposure to solar UVR in the recipients is indicative of a high risk of developing KCs in the same way as the rest of the populace but the immunosuppressive treatment that recipients needs to undergo after the procedure is also a risk factor. (Vajdic *et al*., 2009).

2.3.3.5. Erythema and photoaging

Erythema or sunburn is the most noticeable acute effect of exposure to UVR and results from damage to the DNA of the skin's cells. This condition involves a number of changes in the affected cells (Young, 2006). The red colouring of the skin associated with erythema is caused by an increase in the amount of blood that is transported to the surface of the skin that, together with the influx of cells such as macrophages, neutrophils and pro-inflammatory mediators, forms part of an inflammatory response to the UVR exposure (Bae *et al*., 2009; ICNIRP, 2010). Another characteristic of erythema is the cell death or apoptosis of keratinocytes in the skin that are exposed to UVR above a certain level with an associated feeling of pain (ICNIRP. 2010; D'Orazio *et al*., 2013). After apoptosis, these "sunburnt" cells move outwards towards the stratum corneum where they are removed through the "peeling" of the skin (ICNIRP, 2010). If the photodamage was not severe enough to induce apoptosis, hyperkeratosis or the increased multiplication of keratinocytes in the epidermis leads to the thickening of the epidermis (D'Orazio *et al*., 2013).

Chronic exposure to UVR has also been linked to augmentation of the intrinsic aging of the skin which is referred to as photoaging (Cavinato and Jansen-Dürr, 2017; Lim *et al*., 2017). The features of photoaging includes damage to the extracellular matrix of the skin such as the decrease in the skin's collagen together with increased fragmentation of fibrils as well as increased elastic fibre associated protein and pro-inflammatory proteases (McCabe *et al*., 2020). The changes to the structure of collagen, as well as increased degeneration of the collagen will hinder its function of ensuring the elasticity of the skin (Bae *et al*., 2009). The

damage to the proteins of the skin can be seen on a molecular level long before the clinical manifestation is evident (McCabe *et al*., 2020).

2.4. Genetic factors influencing health effects associated with UVR exposure

The genetic makeup of an individual is a contributing factor in the intensity of the solar UVR-related health effect, both positive and negative, experienced by an individual. The most prominent genetic variation with regards to photoprotection against solar UVR sensitivity is the difference in melanin content of skin although the thickness of the stratum corneum layer of the epidermis also provides some protection (Swalwell *et al*., 2012).

2.4.1. Melanin content of the skin

Melanin is a biopolymer pigment found in specialised cells called melanocytes in both skin and hair (Yamaguchi *et al*., 2007). The specific pigment absorbs UVR, as well as acting as an antioxidant (Brenner and Hearing, 2008). The melanin is synthesised by melanosomes present in melanocytes. Melanosomes are organelles that are similar to lysosomes. In addition to the synthesis function of the melanosomes, they are also involved in the movement of melanin from the melanocytes to keratinocytes (Fajuyigbe and Young, 2016).

An individual's skin colour is determined by factors such as the ratio of the two different types of melanin that can be found in the skin (Rachmin *et al*., 2020). Pheomelanin, which has red or yellow tones, is more prominent in lighter individuals with red hair while the darker brown or black eumelanin is more prominent in darker individuals (Yamaguchi *et al*., 2007; Brenner and Hearing, 2008). Eumelanin absorbs solar UVR much more effectively than pheomelanin (Rachmin *et al*., 2020). The differences in the level of pigmentation between the different areas of an individual's body tends to stay the same regardless of whether the individual's is heavily or lightly pigmented. An example of this is the lighter pigmentation of the soles of the feet when compared to skin found on other body areas. Exceptions to this are genetically increased or decreased melanocyte density, with freckles and vitiligo as respective examples. An individual's genetic makeup determines skin pigmentation factors such as the pattern of melanocytes distribution, the density of melanocytes and the synthesis of different types of melanin (Yamaguchi *et al*., 2007).

Genetic makeup also determines the skin's reaction to solar UVR exposure and the resulting keratinocyte DNA damage (Juzeniene and Moan, 2012). The reaction includes an increase in the density of the melanocytes as well as movement of melanin from the inner to the outer

parts of the epidermis (Yamaguchi *et al*., 2007). Exposure to UVA may result in either immediate pigment darkening (IPD) or delayed tanning, while exposure to UVB is the most prominent UVR region involved in delayed tanning (Shin *et al*., 2014). The occurrence of IPD is a temporary discolouration mostly found in individuals with dark skin which provides a greyish colour to the skin that lasts minutes to a few hours (Ravnbak, 2010; Shin *et al*., 2014). Movement of already present melanin from one area to another is thought to be a possible mechanism in IPD although the creation of new melanin has also been put forward (Fajuyigbe and Young, 2016). Delayed tanning involves the synthesis of new melanin in the skin (Ravnbak 2010).

The larger melanosomes and associated increased in melanin secretion in the skin of darker individuals provides greater photoprotection than the smaller melanosomes found in lighter skin individuals. This is achieved through greater absorption or scattering of the UVR before it reaches the deeper layers of the skin where it can have an effect on DNA (Brenner and Hearing, 2008; Agbai *et al.,* 2014). The photoprotective characteristics of melanin found in dark skin are found in the basal layer of the epidermis (Fajuyigbe and Young, 2016). Skin that contain very high levels of melanin such as those of Black individuals from West Africa, provides protection against DNA damage including lesions such as cyclobutane pyrimidine dimers (CPD). This protection in dark skin was 58 times more than the protection provided by the much lower melanin levels found in fair skin (Fajuyigbe *et al*., 2018). When evaluating the distribution of CPD in darkly pigmented skin, most were found in the superficial epidermis and almost none found in the deeper basal layer, whereas a more uniform distribution was found in fair or very light skin colour (Shih *et al*., 2018). However, the genetic predisposition to tan (delayed increase in pigmentation) after exposure to solar UVR provides the individual with only limited protection against subsequent solar UVR exposure (Greinert *et al.*, 2015). It has been found that DNA damage still occurs in all skin phototypes due to solar UVR exposure regardless of the melanin content of the skin (Agbai *et al.,* 2014). Although epidemiologic data has suggested the photoprotective efficiency of melanin found in sun protected or constitutive (see Section 2.4.2 for further explanation) skin against skin cancer and photodamage to DNA, experimental data has not corroborated a similar prevention of photo-immunosuppression and only limited protection against erythema and photolesions found on DNA provided by melanin in either constitutive or facultative skin (Fajuyigbe and Young, 2016). Holman *et al*. (2018) found that almost 30% of Hispanic participants and 13% of African American participants reported that they have experienced erythema in the past during research conducted among adults in the USA.

Photoaging is also common in individuals with increased skin pigmentation but the manner in which photoaging manifests differs with what is found in individuals with lighter skin colour (Chien *et al.*, 2018). The characteristics of photoaging is determined by the level of pigmentation in the skin with lighter individuals exhibiting deep wrinkles and increases in pigmentation (Cavinato and Jansen-Dürr, 2017; Chien *et al*., 2018). In individuals with darker skin, photoaging is also characterised by increased skin laxity, although characteristics such as fine wrinkles were not observed (Chien *et al*., 2018). Chien *et al*. (2018) found that the sun exposed skin of African Americans over the age of 65 years were found to be lighter when compared with younger individuals of the same population group which was different from the increase in pigmentation found in Caucasians of the same age group. Increased redness of the skin was also found in both the older African American and Caucasian groups.

2.4.2. The Fitzpatrick skin phototype system

Efforts have been made to classify the genetic protection that a specific type of skin provides an individual by classifying the skin phototype of the individual (Fitzpatrick, 1988). Fitzpatrick (1988) proposed a classification system where skin is classified by taking into account the skin, hair and eye colour of an individual together with their history of sunburn and tanning after exposure to solar UVR. This classifying system was first only developed for Caucasian skin in 1975 before it was expanded in 1988 to include darker skin phototypes (Fitzpatrick, 1988). Six skin phototype were proposed ranging from type I which refers to individuals with no inherent melanin pigmentations to type VI which refers to individuals with very dark skin that does not burn (Table 1). This classification system has been frequently implemented in clinical settings as it is relatively easy to use, however, the system does have limitations (Choe *et al.,* 2006).

The self-reporting nature associated with collecting information regarding sunburn history makes reliable classification difficult as individuals may not correctly remember their history or understand the stated questions. Some of the terminology used during questioning is also confusing to darker skin individuals such as tanning and sunburn which leads to incorrect answers (Eilers *et al*., 2013). Individuals also tend to judge their skin colour darker than it is in reality (Reeder *et al*., 2010). The misjudgement of skin colour may be influenced by racial identity (Wright *et al*., 2015). The presence of dermatologists to assist in reporting information related to the Fitzpatrick skin phototype characterisation system has shown to improve the reliability of the information, however, an alternative to the existing subjective method has been sought such as the objective determination of skin colour using the measurement of skin reflectance (Ravnbak, 2010; Eilers *et al*., 2013). In a South African study, it was found that

replacing terminology such as burn with ‘skin irritation’ or skin tenderness’ and tanning with ‘skin becoming darker’ result in more accurate self-reported skin colour from people with dark skin (Wright *et al*., 2015).

Table 1: Skin phototype classifications adapted from Fitzpatrick (1988) by Wright *et al*. (2013).

Fitzpatrick skin phototype	Constitutive characteristics	History of sunburn	Continuous UVR exposure estimated to elicit sunburn on untanned skin (Standard Erythemal Dose (SED)*)
I	Fair skin, blue or light eyes and freckles	Always burn on minimal exposure	2-3
II	Red or blonde hair, blue, hazel or brown eyes and freckles	Burns very readily, freckles common	2.5-3
III	Brown hair and blue, hazel or brown eyes	May burn on regular exposure with no protection, tans slowly	2-5
IV	Brown hair and dark eyes	Burns rarely, tans rapidly with minimal exposure	4.5-6
V	Brown eyes and dark brown or black hair	Despite pigment, may burn easily on exposure	6-20
VI	Brown eyes and dark brown or black hair	Rarely burns, through sunburn is difficult to detect on heavily pigmented skin	6-20

Differences in the pigmentation between facultative skin and cumulative skin has been found in some skin phototypes (Markewicz and Idowu, 2020). Facultative skin can be described as skin that has previously been exposed to the sun while constitutive skin has not been exposed to the sun on previous occasions (Ravnbak, 2010). Choe *et al*. (2006) found that although constitutive skin colour of individuals with a Fitzpatrick skin phototype III differed significantly from the pigmentation of the individual’s facultative pigmentation, individuals that fall into the Fitzpatrick skin phototype groups IV and V do not exhibit this significant difference between the two types of skin pigmentations. Facultative skin colour can also increase or decrease due to, respectively, a seasonal increase or decrease in UVR exposure (Thieden *et al*., 2009, Juzeniene and Moan, 2012).

2.4.3. Thickening of the stratum corneum

The increase in the thickness of the epidermis, specifically the stratum corneum, provides additional photoprotection to the skin against UVR exposure (Bech-Thomsen and Wulf, 1996; Gambichler *et al*., 2006). The thickening of the epidermis is caused by hyperkeratosis which

is the increased formation of additional keratinocytes under the influence of epidermal growth factors (D'Orazio *et al*., 2013). Exposure to UVR lead to overall biochemical changes to the structure of the stratum corneum (Lipsky *et al*., 2020). Although exposure to both UVA and UVB has been shown to illicit the thickening response, the response was more noticeable when skin was exposed to UVB (Gambichler *et al*, 2006)

2.5. Environmental and behavioural factors influencing personal UVR exposure

A number of environmental and behavioural factors have an effect on the amount of ambient solar UVR in an area, which in turn affects personal exposure to UVR (Milon *et al.*, 2007; Cahoon *et al*., 2013).

2.5.1. Environment factors influencing UVR exposure

The environmental factors affecting the amount of ambient UVR in an area are the latitude and altitude of the area, the weather conditions, the reflective properties of the area's terrain, time of day and the season (Milon *et al*., 2007; Norval *et al*., 2007; Moldovan *et a*l, 2020).

2.5.1.1. Effect of latitude on ambient UVR

Ambient UVR levels typically increases when traveling closer to the equator and decreases when traveling towards the poles due to the higher inclination of solar radiation in areas at higher latitudes (Corrêa, 2015). Latitude has also been found to be the greatest predictive factor of personal UVR exposure (Cahoon *et al*., 2013). The increase in ambient UVR due to decreasing latitude is more noticeable in the UVB wavelength region than the UVA wavelength region. This difference may be due to the greater distance that UVR must travel through the atmosphere at higher latitudes which allows more opportunity for the absorption of UVB than UVA, as UVB is more readily absorbed by ozone (Bais *et al*., 2015; Corrêa, 2015). In addition, the smaller band of ozone over lower latitude areas results in diminished scattering and absorption of the radiation which may also influence the ambient exposure level (Bais *et al*., 2015).

2.5.1.2. Effect of altitude on ambient UVR

Ambient UVR levels measured in areas with higher altitudes tend to be higher than the ambient UVR measurements recorded in areas at lower altitudes (Milon *et al*., 2007). The altitude effect, measured in percentage per kilometre (%/km), when independent from other factors is caused by the diminished amount of aerosols available at higher altitudes to scatter or absorb UVR from the sun (Aceituno-Madera *et al*., 2011). However, the altitude effect is

also impacted by different factors such as the wavelength of the UVR, the specific albedo (Section 2.5.1.4) or reflective properties of the terrain, atmospheric turbidity and the elevation of the sun found in a specific area, resulting in inconsistent findings from research studies (Blumthaler *et al*., 1997; Pfeifer *et al*., 2006). For example, in Bolivia, Zaratti *et al*. (2003) found that there was an increase of 7 %/km while Pfeifer *et al*. (2006) found an increase range from 4.9 %/km to 8.1 %/km. Aceituno-Madera *et al*. (2011) also found that the altitude effect increased noticeably in areas with altitudes above 700 meters. The effect of the different wavelengths of UVR is illustrated by the increase from 9 %/km to 11 %/km when the wavelength of the UVR changed from 370 nm to 320 nm (Blumthaler *et al*., 1997).

2.5.1.3. Cloud covers and ambient UVR

Clouds can play a role in both increasing and decreasing the ambient UVR in an area depending on the type of clouds (Barnes *et al*., 2019). The ambient UVR is decreased when significant and complete cloud cover, which is grey in colour, is present in an area due to the absorption of UVR (Antón *et al*., 2012; Bais *et al*., 2015). Not only clear, cloudless skies will result in increased ambient UVR. Partly cloudy conditions increase both direct and diffused ambient UVR through the scattering of UVR, as well as the reflecting of UVR from the borders of some types of clouds such as cumulus clouds (Piacentini *et al*., 2001; Antón *et al*., 2012). The impact of UVR on the eyes are also greater under these types of conditions due to the absence of protection mechanisms such as squinting employed during sunny, cloudless conditions (Norval *et al*., 2007).

2.5.1.4. Albedo

Chadyšiene and Girgždys (2008) defines albedo as “the ratio of the sunlight reflected by an object of the light it receives”. The degree of reflection can be given in one of two ways, namely as a percentage or as a number on a scale from zero to one (Chadyšiene and Girgždys, 2008).

Although the total albedo of Earth has been averaged to approximately 30% or 0.3, the amount of UV containing sunlight that is reflected in a specific area is depended on the type of surface that is present in that area (Norval *et al*, 2007; Chadyšiene and Girgždys, 2008). The type of surface that reflects the largest portion of solar UVR that falls on that surface is snow at approximately 90% or 0.9, followed by sand at 10% or 0.1, still water at 5% or 0.05, choppy water at 20% or 0.2 and, lastly, green vegetation with an albedo of 2 to 3% or 0.02 to 0.03 (Diffey, 2002; Norval *et al*, 2007). There is also a difference between the amount of UVA and UVB that is reflected, with UVB being reflected to a lesser degree than UVA (Chadyšiene and Girgždys, 2008).

However, the albedo values of natural surfaces have been found to change during the day with the highest at noon due to the lower zenith angle of the sun. In addition, the albedo of a specific location may also vary due to change such as agricultural activities and deforestation. Care should also be taken when using albedo values found in different databases that are available. Some albedo values ascribed to snow may have been overestimated because the antagonistic influences of factors such as rough terrain and shading were not taken into account (Gueymard *et al*., 2019).

2.5.1.5. Variations in ambient UVR due to the time of day and the seasons

Ambient UVR in an area varies with the time of day and season (Corrêa, 2015; Wainwright *et al*., 2017). The position of the sun also plays a role in the level of ambient UVR at a specific time of day. The angle of the sun during sunrise and sunset results in a longer pathway, that UVR must travel and consequently interact with more aerosol molecules (Corrêa, 2015). In contrast, the absorption and scattering of UVR is minimal during the middle part of the day resulting in the maximum ambient UVR measured at or near noon (Casale *et al*., 2015; Wang *et al*., 2017).

Differences in the degree of absorption of UVR by ozone, the position of the sun relative to the earth and the seasonal variation in cloud cover are all factors that influences a season's ambient UVR (Casale *et al*., 2015; Corrêa, 2015). Typically, ultraviolet index (UVI) levels are highest in summer and lowest in winter, with similar UVI readings in spring and autumn seasons (Wainwright *et al*., (2017). The differences in ambient UVR levels between the four seasons is also illustrated by the seasonal pattern observed in the vitamin D status of individuals (Van der Mei *et al*., 2007). The season influences individual's behaviour regarding the time of day and the length of time that a person will spend outside, influencing their personal UVR exposure (Wainwright *et.al*., 2017).

2.5.2. Behavioural factors influencing personal UR exposure

Behavioural factors such as the posture that person assumes while in the sun as well individual decisions on the total amount of time and time of day spent in the sun has a definite impact on personal UVR exposure (Downs *et al*., 2014; Wainwright *et al*., 2017; Wang *et al*., 2017).

2.5.2.1. Effects of posture on personal UVR exposure

Individuals performing the same activity in the same area at the same time may receive different levels of UVR exposure due to individual differences in posture (Kimlin *et al*., 2006). For example, cyclists racing in the same charity race in Australia, at the same time, received different UVR exposures due to the different postures they assumed while riding their bicycles (Kimlin *et al*., 2006). Taking this variation into account, it is not unexpected that the UVR exposures of individuals that perform different activities that require different postures and patterns of movement also receive different levels of UVR exposure (Siani *et al*., 2011). This difference is not only in the overall UVR exposure, but also in the UVR exposure of the different anatomical sites of the body, due to their relative position with regards to the sun (Kimlin *et al*., 2006; Wang *et al.*, 2017). Anatomical areas received relative more UVR when turned towards the sun while receiving relatively less when turned away from the sun. There is an increase in the exposure of different anatomical areas to both direct UVR and scattered UVR. This increase is also observed with regards to the UVR reflected from the ground towards an individual (Wang *et al*., 2017).

Horizontal areas of the body such as the vertex, or top of the head, have been shown to receive the bulk of UVR when compared to vertical areas. Cyclists received the lowest UVR exposure on their ankles which is also a vertical surface (Kimlin *et al.*, 2006). In postures where certain anatomical sites are blocked from the sun by other sites, there may also be a decrease in the UVR reaching the blocked area (Nardini *et al*., 2014a). Parisi *et al*. (2003) found that the posterior side of the lower limbs received UVR at levels that were between two and 10 times less that the anterior side of the same anatomical area due to shading by other body parts as well as the chair that was sat on. A study conducted in Italy to evaluate the anatomical distribution of the UVR received by the different anatomical areas of farmworkers while working in strawberry fields, found that during summer (specifically June) the farmworkers' forearms, foreheads, cheeks and the nape of the neck received, respectively, 55.13%, 51.38%, 42.37% and 104.96% of the ambient UVR (Nardini *et al.,* 2014b). UVR exposure of the nape of the neck also exceeded the ambient UVR (Milon *et al*., 2007) in construction workers in Switzerland. Milon *et al*. (2007) gave a possible explanation that the body part may be more perpendicular to the sun than the horizontal plane on which the ambient UVR was measured as it would be in cases where the sun is not placed directly in the middle of the sky. Wright *et al.* (2004) also raised the possibility of the influence of reflective UVR in the specific area that may influence UVR exposure.

The change of the position of the sun during the day has an effect on the UVR exposure of certain anatomical sites meaning that if the same position is maintained throughout the day, there will be changes to the UVR received due to the sun moving in relation to the body (Wright *et al*., 2004; Nardini *et al*., 2014a). This change means that the different body areas receive their maximum UVR exposures at different time periods as dictated by the angle towards the sun (Nardini *et al*., 2014a; Wang *et al.*, 2017). The repositioning of the sun will also influence the body sites that block UVR from other body sites (Nardini *et al.*, 2014a).

2.5.2.2. Sun seeking behaviour influenced by environmental factors, social factors and activity scheduling

Factors such as the outside maximum temperature, changes in outdoor behaviour due to change in season, the tendency to sunbathe, the individual's sun sensitivity and gender have an effect on the time period spent outside in the sun (Bodiwal *et al.*, 2003; Van der Mei *et al*., 2007; Cahoon *et al*., 2013; Xiang *et al*., 2015). The period time spent outside in the sun and the time of day of the period of time, are highly determined factors in an individual's personal exposure to solar UVR (Downs *et al*., 2014; Wainwright *et al*., 2017). During days with higher maximum temperatures, people tend to spend more time outside while wearing clothing that allows more skin to be exposed to the sun. However, when the maximum temperature is above 30 °C it was found that there is a slight decrease in the time spent outside (Xiang *et al*., 2015; Schmalwieser *et al*., 2019). The season has an effect on the time of day that individuals spend time outside with a tendency to spend time outside earlier and later during summer than winter. During winter, most of the time spent outside occurs during 10:00 to 14:00 (Wainwright *et al*., 2017).

Sunbathing involving exposure of skin on body areas that are normally covered with clothes such as the trunk to acquire a bronzed skin colour, is culturally acceptable in Western countries, has led to increased exposure solar UVR (Bodiwal *et al*., 2003; Gao *et al*., 2014). Individuals who tend to experience painful erythema due to their skin's reaction to solar UVR also tend to spend less time in the sun (Cahoon *et al*., 2013). Gender also may have an effect on the time spent outdoor with men spending more time outdoors than women (Xiang *et al*., 2015).

As previously stated in Section 2.5.1.5, the maximum ambient UVR level is present during the middle of the day or approximately 12:00 (Casale *et al*., 2015). Therefore, it would be beneficial to schedule outdoor activities earlier or later in the day to decrease personal exposure to UVR. In occupational environments the scheduling of workers' lunchbreak to fall

during the time of maximum ambient UVR may be a valuable tool in protecting workers from excessive personal UVR exposure as workers may be able to sit in the shade during this time (Nardini *et al*., 2014b). This protective potential is illustrated by the evaluation of personal UVR exposure of New Zealand outdoor workers where lowest hourly mean percentage of ambient exposure occurred during the time period of 12:00 to 13:00 although the highest ambient UVR was measured during this time. However, a large number of workers may be unable to schedule their work day to take advantage of this solar UVR protective measure (Hammond *et al*., 2009).

2.5.3. Photoprotection

There are protective measures that can be taken to enhance or improve the natural photoprotection provided by an individuals' genetics or in cases where they cannot change their schedule to work in the shade or low ambient UVR time of the day (Milon *et al*., 2007; Al-Jamal *et al*., 2014). These include staying in the shade or wearing protective clothing and sunglasses, as well as using sunscreen (Jansen *et al.*, 2013a).

2.5.3.1. Provision of shade to outdoor workers

The provision of shade is a photoprotective engineering control measure that is recommended by several sources including the Cancer Association of South Africa (CANSA) (2018) as well as researchers such as Hammond *et al*. (2008) and Al-Jamal *et al*. (2014). Shade may be provided in several ways such as trees, umbrellas or fixed built structures such as awnings, buildings and walls (Lucas *et al*., 2016; Ou-Yang and Shyr, 2017). A study that evaluated the facial solar UVR exposure of Austrian farmers showed that an apple farmer that moved part of his harvesting operation to a shady area or indoors received a definite reduction in his exposure when compared to farmers who conducted the process completely in the sun (Schmalwieser *et al*., 2010).

Regardless of the recommendations to provide shade to individuals, shade does not always provide complete protection as the nature of the shade may vary. Factors that influence the effectiveness of shade as a photoprotective measure include physical factors such as the size and shape of the shade as well as the material that the source of the shade is made of (Ou-Yang and Shyr, 2017). In the case of trees, the density of the foliage of a specific tree also acts as part of the physical factors (Lucas *et al*., 2016). Additionally, environmental factors such as albedo, the percentage of sky covered with clouds and the wavelength of the UVR influences the ratio of diffuse UVR to total UVR which may increase exposure under the source of shade. The behaviour of the individual utilising the shade with regards to their position and

orientation under the source of shade can be classified as the human behaviour factors that influences the effectiveness of shade (Ou-Yang and Shyr, 2017).

2.5.3.2. Use of sunscreen

Sunscreen, in the form of red ochre, has been widely used in areas such as the southern and eastern parts of Africa since approximately the Middle Stone Age. Red ochre, after being mined, is still often used by the Ovahimba people of northern Namibia and, according to ethnographic accounts, used by the Tswana and Xhosa people, as well as San hunter-gathers of South Africa (Rifkin *et al*., 2015). During an evaluation of ochre's photoprotective properties when used on human skin by Rifkin *et al*. (2015) it was found that the notable photoprotective effects of red ochre was increased when ochre had a high iron content as well as a smaller grain size. In contrast to this traditional form of sunscreen, the first sunscreen that was made commercially available was produced in 1928 in the USA (Jansen *et al*., 2013b).

Originally, modern and commercial sunscreens were designed only to protect against the erythema-inducing action of UVB, but later formulations were designed to protect against the effects of exposure to both UVB and UVA. This shift in the approach to the design of a sunscreen was aimed at achieving protection against both the erythema effect of both UVR regions but also systemic negative effects such as immunosuppression (Young *et al*., 2017). A number of different active ingredients are used in topical sunscreen to achieve this required photoprotective effect including the organic filter oxybenzone, antioxidants such as vitamins A, C and E (to counter ROS created by UVR exposure), as well as inorganic nanoparticles such as titanium dioxide and zinc oxide (Lim *et al*., 2017; Young *et al*., 2017). Subcutaneous and oral means of photoprotection is also being investigated such as the extract from the fern *Polypodium leucotomos*, the synthetic peptide afamelanotide which is structurally similar to the α–melanocyte-stimulating hormone and the active amide form of vitamin B3 (nicotinamide) (Lim *et al*., 2017). Medicinal plants used traditionally by communities such as the Xhosa people in the Eastern Cape Province of South Africa as protection against solar UVR exposure is also being investigated for their use in commercial sunscreens (Mwinga *et al*., 2019). The measurement of the efficacy of the different types of sunscreens is accomplished through a number of regulations (Young *et al*., 2017).

Different countries around the world mainly use standards from two organisations to determine the efficacy of a sunscreen in the form of sun protection factor (SPF), which is primarily an index related to protection against UVB, as well as testing of protection provided against UVA. These two organisations are the Food and Drug Administration (FDA) of the USA and the

International Standards Organisation (ISO). South Africa, together with amongst others Europe, uses the ISO 24444:2010 standard (SPF *in vivo*), ISO 24442:2011 (UVA PF *in vivo*) and the ISO 24443:2012 standard (UVA PF *in vitro*), while the USA uses the FDA 2011 standard for determining SPF *in vivo* and UVA PF *in vitro* (Young *et al*., 2017).

Although a sunscreen is shown to provide adequate protection against the broad spectrum of UVR under laboratory testing conditions, it will not provide the advertised photoprotection if the correct amount of the product is not applied or the product is not reapplied after a period of time to compensate for loss due to sweating or contact with water (Young *et al*., 2017). The Australian and New Zealand Sunscreen Summit Policy group recommended that individuals living in these countries apply 2 mg of sunscreen for every square centimetre of exposed skin which should be reapplied every two hours (Yamada *et al*., 2020). Despite these recommendations, a study found that sunscreen users only applied approximately 0.5 mg/cm^2 to 1.5 mg/cm^2 of sunscreen in contrast to the 2.0 mg/cm^2 that is used during laboratory testing conditions of sunscreen (Young *et al*., 2017). These behavioural factors that may be linked to the knowledge of the sunscreen user is an important factor in the effectiveness of sunscreen in a photoprotection programme (Jansen *et al*., 2013b)

2.5.3.3. Photoprotective clothing

The type of clothing, including hats, worn by an individual can either diminish or increase the amount of UVR that is allowed to reach the skin (Jansen *et al*., 2013a). There are a number of factors that influence the UVR protective qualities of a fabric including the thickness of the material and the colour that the clothes are made of (González *et al*., 2008). The thicker the material, the higher the UVR protection that it provides as shown by the high level protection provided by denim and the low level of protection provided by silk (Ghazi *et al*., 2010). Darker colours such as black and blue provide good UVR protection independent other factors while bleached or white fabrics provided no measurable UVR protection. The UVR protection of beige fabrics sometimes referred to as being in a grey state is highly dependent on other factors such as the tightness of the weave of the fabric (Dubrovski and Golob, 2009).

The tightness of the weave of the fabric, determined by the weave type, also influences the level of UVR protection provided by a specific fabric. A weave type such as plain weave provides the least amount of UVR protection when compared with other weave types such as satin and twill. The reason for this lack of protection is the presence of stable and uniform macropores that allow UVR more unobstructed space to move through the fabric. In fabrics constructed using a weave type such as satin, the macropores are small and relatively

unstable reducing the free space available for UVR to travel through, thus increasing the protection against UVR (Dubrovski and Golob, 2009).

Treatment of clothes may either increase or decrease a fabric's UVR protection ability (Jansen *et al*., 2013a; Kan and Au, 2014). Kan and Au (2014) found that the addition of an UV absorber to fabric led to an increase in UVR protection ability from poor to very good, while bio-polishing (the use of an enzyme to enhance smoothness) increased UVR protection by 35%. Bleaching and removal of starch from the fabric may result in decreased UVR protection. Additionally, factors such as stretching ability and desizing may increase UVR permeability while hydration of a material may either increase or decrease UVR permeability dependent on the type of material (Jansen *et al*., 2013a).

In aid of quantifying the protection that clothing may provide against UVR exposure, the use of the UV Protection Factor (UPF) originated in Australia (AS/NZS 4399:1996) before becoming widely used in other countries (Jansen *et al*., 2013a). In South Africa, the Cancer Association of South Africa (CANSA) provides certification of this factor for clothing as part of SunSmart initiative (CANSA, 2016). The UV protection factor has been defined as the "ratio of erythemally effective solar UVR exposure on exposed skin to that received through the fabric" (ICNIRP, 2010). In laboratory conditions, the measurement of UVR transmission through fabric is measured using spectrophotometric methods (Urbas *et al*; 2012). Clothing with a measured UPF of 50 or more is classified as providing excellent UVR protection while fabrics with a measurable UPF falling in the range of 30 to 49 or 15 to 29, are classified as provided, respectively, very good or good UVR protection (SunSmart, 2018).

The wearing of a hat while outside and exposed to solar UVR may provide some photoprotection to the areas of the face and neck if the hat is designed correctly. Factors such as the width of the brim of the hat, the fabric that the hat is made of and the type of weaving type used, influences the amount of photoprotection provided (Jansen *et al*., 2013a). The use of the correct hat can decrease the solar UVR that reaches the eyes by up to approximately 50% (West *et al*., 1998). Baseball style caps that only provide shade to a small region of the face provides the least amount of photoprotection while broad brimmed hats provided the highest level of photoprotection to both the face and back of the neck (Gies *et al,* 2006). A broad-brimmed hat may provide photoprotection up to a SPF of 7 for the nose as well as a SPF of 5 for the neck (Jansen *et al*., 2013a). The AS/NZS 4399:2017 standard for sun protective products requires that broad brimmed hats for adults have a brim of at least 7.5 cm

(King *et al*., 2018). Although hats provided a measure of photoprotection, it should be used in conjunction with other photoprotective measures (Gies *et al*., 2006).

2.5.3.4. Sunglasses

The wearing of sunglasses with lenses tinted with a UVR absorbent coating forms part of recommendations for photoprotection of all individuals, regardless of their skin phototype by organisations such as the American Academy of Dermatology (Cestari and Buster, 2017). Of the three national standards that have been drafted and are currently in use, only the Australian standard (AS/NZS 1067:2003) and European standard (EN 1836:2005) are mandatory with the USA standard (ANSI Z80.3) being voluntary. Additionally, only the Australian standard requires an independent verification of compliance of produced sunglasses to the specific standard (Jansen *et al*., 2013a). Factors such as the size, shape, potion of the head while wearing the sunglasses and exposure conditions influence the level of photoprotection provided by sunglasses (Backes *et al*., 2019)

The correct use and fit of sunglasses are of vital importance in the amount of photoprotection provided to the eyes (Almutawa *et al*., 2013). The optimum fit of a pair of sunglasses is as close as possible to the face; even a seemingly insignificant gap of 6 mm may result in a considerable increase in the UVR exposure of the eye from approximately 15% to 55% (Krutmann *et al*., 2014). Due to the contribution of reflected and scattered UVR to the total amount of UVR that reaches the eye through a pair of sunglasses, the design of the sunglasses needs to focus on the size of the lenses and the overall shape of the frame. The optimum design should have a vertical lens diameter that is large enough to block a large amount of the UVR that may potentially reach the eyes. Although this is an important design feature of sunglasses, only AS/NZS 1067:2003 provides requirements for the vertical diameter of lens namely 28 mm in the case of adults and 24 mm in the case of children. Furthermore, the optimal design of the frame of a pair of sunglasses provides the most coverage as possible on both sides to prevent UVR from entering from these areas (Almutawa *et al*., 2013). Close fitting goggles have been found to provide the most photoprotection. Although large sized sunglasses provide more photoprotection than medium sized sunglasses, they do not fit close to the nose in some cases and, therefore, do not provide sufficient protection against reflective solar UVR (Backes *et al*., 2018)

Different polymers used in the production of sunglass lenses such as the thermoplastic polycarbonate and urethane based Trivex, together with different anti-reflective and anti-UVR coatings also contribute to the different UVR shielding abilities of different types of sunglasses

(Jansen *et al*., 2013a; Krutmann *et al*., 2014). The colour of the sunglass lens does not play a significant role in the UVR shielding ability by itself, with dark lenses potentially adding to the UVR that reaches the inside structures of the eye due to the increased pupil dilatation caused by the blockage of visible light (Almutawa *et al.*, 2013).

2.5.3.5. Effect of knowledge and attitudes on personal UVR exposure

The knowledge and attitude that individuals possess regarding solar UVR influences the individuals' behaviour, which in turn influences their exposure to solar UVR (Carley and Stratmann, 2015). Women tend to have a higher level of knowledge regarding the health effects of exposure to solar UVR and the associated control measures as was found by both Gao *et al*. (2014) during their study amongst North-eastern Chinese undergraduate medical students and Oduntan *et al.* (2010) during their study amongst South African university students. Although a higher level of education may result in a higher level of knowledge regarding solar UVR when compared to individuals who have a lower level of education, both of the studies mentioned above found that it does not necessarily result in a comprehensive knowledge regarding the subject (Oduntan *et al*., 2010; Gao *et al.*, 2014; Yan *et al*., 2015). Although the vast majority of university students knew that excessive exposure to solar UVR has negative health effects, they did not know all of the associated health effects. The negative health effects related to exposure of the eyes to solar UVR such as cataracts, macular degeneration and pterygium were the group of health effects that they had the least knowledge of (Oduntan *et a*l., 2010; Gao *et al.*, 2014). Individuals with lighter skin that experience erythema easily also tend to have more knowledge regarding the risks associated with excess exposure to solar UVR (Fitzpatrick skin phototype I or II) than individuals with darker skin (Fitzpatrick skin phototype III or IV) (Yan *et al*., 2015). In a South African context, White and Indian individuals tend to have more knowledge on the subject than Black African individuals (Oduntan *et al*., 2010). The effect of age on the amount of knowledge regarding solar UVR is uncertain as some studies such as Yurtseven *et al*. (2012) found younger individuals had less knowledge while Yan *et al*. (2015) found the opposite with younger individuals possessing more information than the older members of their community.

Educating outdoor workers regarding the hazards of excessive exposure to solar UVR and how to work safely in the sun is an important part of preventing the development of negative health effects related to solar UVR (BSD, 2014). In addition, evidence collected in New Zealand and Australia showed that the perception of outdoor workers of workplace support such as education, improves compliance with protection measures (Reeder *et al.*, 2013; Janda *et al*., 2014; Rye *et al.,* 2014). The positive impact of a successful photo-education program is

not only evident in the increased protection of the workers themselves but also in the knock-on effect where the workers' families are also informed about the ways to protect themselves while in the sun (Glanz *et al*., 2007)

2.6. Use of photoprotective measures by agricultural workers

Kearny *et al*. (2014) advocated for the implementation of effective educational intervention as to improve the use of photoprotective measures by agricultural workers such as farmers and farmworkers. Research conducted in various countries studying the use of photoprotective measures by farmers and other agricultural workers indicated that wearing a hat was a photoprotective measure that was often used (Table 2). However, the hats were not always wide-brimmed hats (Salas *et al*., 2005; Reeder *et al*., 2013). Reasons why broad brimmed hats were not used include that that farmworkers wore billed or baseball caps because it did not interfere with their work in the orchards (Salas *et al*., 2005) and that wearing caps, especially those with logos on them, was also been identified as being part of the culture of a country and instrumental in workers choosing that type of hat while working outside (Reeder *et al*., 2013).

Agricultural workers also used other types of photoprotective measures such as wearing sunscreen, sunglasses and long sleeved clothing (Kearney *et al*., 2014). The use of sunscreen sunglasses varied between studies as reported in Table 2. Although removing the need for the workers to work outside in the sun or manage the time spent outside would be the most effective way to prevent overexposure to solar UVR, it is not always possible (Greinert *et al*., 2015; Hammond *et al*., 2009) which may result in this method of controlling exposure to solar UVR not being used very often.

The development of photoprotective programs that are designed specifically for agricultural sectors are needed (Salas *et al.*, 2005; Backes *et al*., 2017; Zink *et al*, 2017). Factors that would be considered in these programs include the impact of working on farms with different crops and that some of these workers are already using protection measures for other hazards they encounter during their work (Salas *et al*., 2005). The effect of gender should also be included in the process as it was found that the different genders tended to prefer different types of photoprotective measures (Zink *et al*., 2017).

Table 2: Use of photoprotective measures by agricultural workers (2005 to 2018)

Specific occupational group	n	Geographical location	The photoprotection measures use that was evaluated (%)	References
Farmworkers	326	California, USA	Protective clothing (75%) Hat with wide brim (25%) Sunscreen (2.5%) Limiting sun exposure (1%) Sunglasses (95%) Any hat (99.7)	Salas *et al* (2005)
Viticulture	83	New Zealand	Wore any hat (88%) Wore a wide-brimmed hat or with flaps (34%) Wore a long-sleeved shirt (57%) Wore other protective clothing (23%) Wore sunglasses (60%) Used shade (12%) Limit exposure to solar UVR (5%) Wore sunscreen on face (25%) Wore sunscreen on all exposed skin (59%)	Reeder *et al* (2013)
Farmers	106	New Zealand	Wore any hat (89%) Wore a wide-brimmed hat or with flaps (44%) Wore a long-sleeved shirt (56%) Wore other protective clothing (15%) Wore sunglasses (47%) Used shade (6%) Limit exposure to solar UVR (7%) Wore sunscreen on face (24%) Wore sunscreen on all exposed skin (20%)	
Agricultural workers	1538	Switzerland and France	Hat (48.6%) Sunglasses (18.3%) Sunscreen (11.9%) Long-sleeved shirt (6.8%) Shade (9.9%)	Backes *et al*. (2017)
Farmers	213	Southern Germany	Always wore sunscreen (5%) Often wore sunscreen (14%) Always wore a hat (21%) Often wore a hat (26%) Always wore a long-sleeved shirt (2%) Often wore a long-sleeved shirt (8%) Always wore long pants (21%) Often wore long pants (24%)	Zink *et al*. (2017)
Skilled agricultural workers	18	Germany	Wore a shirt that covered shoulders (89%) Applied sunscreen to body (42%) Applied sunscreen on face (37%) Wore a hat (33%) Stayed in the shade (29%) Wore sunglasses (17%)	Schneider *et al*. (2018)

2.7. Solar UVR occupational exposure limits

An UVR occupational exposure limit consisting of a biological effective dose that is considered safe has been set by the American Conference of Governmental Industrial Hygienists (ACGIH), the International Committee for Non-Ionizing Radiation (ICNIRP), as well as the International Radiation Protection Association (IRPA) using the ACGIH action spectrum. This exposure limit is given as 30 J/m^2 or 0.3 SED for 8 hours and differs from the exposure limit set using the International Commission of Illumination (CIE) action spectrum (Moehrle *et al*., 2003; ICNIRP, 2010). An action spectrum is the 'a plot of wavelength versus the reciprocal of the dose required for a given photobiological outcome (usually expressed on a log scale)'

(Young *et al.*, 2017). The action spectrum is in most cases normalized to unity at a specific wavelength. This chosen wavelength is the wavelength at which the biological response is the greatest which is 298 nm. The biological response that is usually referenced in the action spectrum is erythema caused by UVR (Siani *et al*., 2011).

The SED unit, or standard erythemal dose unit, can be defined as the "equivalent to an erythemal effective radiant exposure of 100 J/m^2" with "one SED equivalent to an erythema effective radiant exposure of 100 J/m^2" (EN 14255-3:2008). The SED unit has been designed that it is dependent on an individual's skin phototype and associated sensitivity to UVR (Young *et al*., 2017). Any value taken from the CIE action spectrum is 3.63 times that of a value from the ACGIH action spectrum, resulting in the calculation of the CIE UVR exposure limit as 109 J/m^2 or 1.09 SED for eight hours (EN 14255-3:2008). The CIE UVR exposure limit is also used as a range of 1.0 to 1.3 SED (ICNIRP, 2010). However, the existing occupational exposure limits have limitations. For example, there is no adjustment made to these exposure limits to incorporate the individual's existing photoprotection (Milon *et al*., 2007). The ICNIRP have stated that this is the exposure limit is a conservative approach that assumes that the worst case scenario is present and that they are aware that these exposure limits may not be precise (ICNIRP, 2020)

2.8. Occupational solar UVR exposure of non-farming outdoor workers

Individuals employed in occupations that involve a significant percentage of outdoor work will not be able to completely avoid exposure to solar UVR (Moehrle *et al*., 2003). Certain occupations have been identified as posing a high risk of exposure to UVR including construction and agriculture as stated in Section 2.1. Other occupations that fall in this category include landscaping labourers, fishermen and other workers on fishing vessels, as well as roofers (Peters *et al*., 2012). Recommendations have also been made to evaluate the personal UVR exposure of workers working on a solar power system site has they may be exposed to excessive levels of solar UVR (Rascón *et al*., 2016).

Assessments of the personal solar UVR exposure of construction workers have been studied in a number of countries. The findings of these studies showed that Spanish construction workers were exposed to a mean of 6.11 SED/day, Canadian workers in land based construction and marine construction were exposed to 1.30 SED/day and 1.28 SED/day, respectively while Eastern European outdoor construction workers' exposure ranged from

1.28 to 6.40 SED per day (Serrano *et al*., 2013; Peters *et al*., 2016, Moldovan *et al*., 2020). In addition, Polish construction workers were exposed to a median of 20.26 SED/day and Swiss construction workers were exposed to 11.9 SED/day (Milon, *et al*., 2007; Wolska, 2013). Both German mountain guides' average daily exposure to solar UVR of 6.6 SED and a selection of New Zealand workers' average daily solar UVR exposure of 5.32 SED exceeded the CIE occupational exposure limit (Moehrle *et al*., 2003; Hammond *et al*, 2009). Danish outdoor workers in general were exposed to 2.3 SED per day during summer (Grandahl *et al*., 2018). In addition, it was found that Australian teachers exceeded the ACGIH threshold limit values (TLV®) in 17 minutes or 170 minutes of doing playground duty in an open sunny playground or shady area, respectively (Downs *et al*., 2014). Life guards in four cities in the USA were also exposed to high levels of UVR with a median UVR exposure of 3.3 SED per day and 65% exceeding the ACGIH TLV® (Gies *et al*., 2009a). Individuals who took part in expeditions to Antarctica were also exposed solar UVR at levels that exceeded occupational exposure limits 80% of the time (Gies *et al*., 2009b)

Variation in the personal UVR expose of individuals in some occupations has been observed, for example, Physical Education teachers are potentially being exposed to more than 20 times the UVR that class room teachers are exposed in an Australian study (Downs *et al*., 2016). Serrano *et al*. (2014) also found this type variation within Spanish construction workers due to differences in the postures adopted to perform different kinds of work as well as the setting that the work activities were carried out. This is in line with the information provided in Section 2.5.2.1.

2.9. Occupational solar UVR exposure of outdoor farmworkers

Outdoor farmworkers, as well as gardeners, landscapers and horticultural workers are at a risk of being exposed to high levels of UVR when compared to indoor workers and some other job types (ICNIRP, 2010; Schmalwieser *et al*., 2010). This increased risk is shown by the evaluation of the UVR exposure of New Zealand horticultural workers which found that they were exposed to an average level of solar UVR of 5.61 SED per day with a range of between 0.29 and 23.71 SED, as measured on the scapular area of their upper back. Researchers noted that behavioural factors such as the choice of rest area (i.e. shaded, unshaded etc.) played a part in each individual's personal exposure (Hammond *et al*., 2009). Canadian landscapers were exposed to a daily mean of 5.5 SED and 27.6% of the ambient solar UVR while Danish gardeners were exposed to 2.3 SED per day during summer (Grandahl *et al*., 2018; Peters *et al*., 2019).

Similarly, the type of crop that is being cultivated may also has an effect on the level of UVR exposure due to different work environments and activities as dictated by the crop (Salas *et al*., 2005). Researchers found that the solar UVR exposure measured on various anatomical areas of Italian farmworkers working in strawberry production were influenced by the scheduling of their work during the day. The workers' exposure ranged from 0.48 SED to 1.24 SED on the forearm, 0.43 SED to 1 SED on the forehead, 0.39 SED to 0.95 SED on the cheek and 0.85 SED to 2.29 SED on the nape of the neck (Nardini *et al*., 2014a). Vineyard workers in the Tuscany area of Italy experienced UVR on their back, at the top near the neck, that ranged from 10.5 SED to 20.7 SED (average of 14.5 SED) during spring, 7.1 SED to 17.9 SED (average 10.0 SED) and a range of 1.8 SED to 3.0 SED (average 3.3 SED) (Siani *et al*., 2011). The differences in the measured UVR exposure on the same anatomical area may be explained by the differences in work activities due to the different crops, in conjunction with other environmental factors.

Bodekær *et al*. (2015) determined that Polish, Austrian and Danish farmers received occupational and leisure time solar UVR exposure that exceeded the UVR exposure limit standard recommended by the CIE on more than a quarter of the days of the study, while Spanish farmers' solar UVR exposure exceeded the exposure limit on more than half of the days in summer. The average personal solar UVR exposure measured by data logging UVR dosimeters placed on the wrists of farmers varied from country to country with farmers in Poland receiving an average of 1.7 SED per day, farmers in Denmark received 1.5 SED per day, farmers in Spain received 2.6 SED per day while farmers in Austria received 1.4 SED per day (Bodekær *et al*. 2015). Schmalwieser *et al*. (2010) also found that the UVR exposure on the faces of Austrian farmers also exceeded the recommended as standard as the mean daily exposure was measured as 2.99 SED with a daily maximum exposure of 14.2 SED. The percentage of the ambient UVR that was measured in this study ranged from 3% to 26% (Schmalwieser *et al*., 2010). The difference between the two UVR exposure reported for Austrian farmers may be due to the different positioning of the electronic dosimeter with Schmalwieser *et al*. (2010) positioning the instrument on the forehead while Bodekær *et al*. (2015) placed the instrument on the wrist of the farmers.

2.10. The health risk of excess solar UVR exposure of outdoor workers in South Africa

Ambient solar UVR measurements were used to estimate the sunburn risk posed to South African outdoor workers at sites with biometers measuring ambient solar UVR spanning a time period of one year. The ambient solar UVR measured during summer months in Cape Point

and Durban posed an erythemal risk to outdoor workers of all skin types. Even the solar UVR exposure during winter months posed a risk to workers with skin types I to III (Wright *et al*., 2013). Earlier additional ambient solar UVR measurements in Pretoria, Port Elizabeth and Cape Town (sites with biometers) indicated a health risk being posed to workers of all skin types in the areas during both winter and summer, as well as in summer in De Aar (Wright *et al*., 2011). A case study done in Pretoria found that an outdoor worker experienced an average of 84.11% of the ambient solar UVR during a normal work day which indicate a high risk of excessive solar UVR exposure (Makgabutlane and Wright, 2014). In addition, workers that provided security at parking areas in Potchefstroom, South Africa were exposed to 0.29 SED per day on their arm (Nkogatse *et al*., 2019)

2.11. Conclusion

The literature study described the importance of balancing an individual's exposure to solar UVR as it can both be a necessity and a risk to health. The different factors that may influence personal UVR exposure were discussed with these factors ranging from environmental factors such as latitude of an area and the time of day to behavioural factors such as the knowledge regarding solar UVR and the use of photoprotection. Emphases was placed on the solar UVR exposure of outdoor workers, specifically farm outdoor workers which is of vital importance to South Africa as a large part of both the formal and informal workforce participates in agricultural activities.

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CHAPTER 3: ARTICLE I

Linde K, Wright CY, Du Plessis JL. (2020). Subjective and objective skin colour of a farmworker group in the Limpopo Province, South Africa. 2020 *Skin Res Technol;* **26(6)**:923-931.

3.1. Instructions to authors

Skin Research and Technology is a clinically-oriented journal on biophysical methods and imaging techniques and how they are used in dermatology, cosmetology and plastic surgery for noninvasive quantification of skin structure and functions. Papers are invited on the development and validation of methods and their application in the characterization of diseased, abnormal and normal skin. Topics include blood flow, colorimetry, thermography, evaporimetry, epidermal humidity, desquamation, profilometry, skin mechanics, epiluminiscence microscopy, high-frequency ultrasonography, confocal microscopy, digital imaging, image analysis and computerized evaluation and magnetic resonance. Non-invasive biochemical methods (such as lipids, keratin and tissue water) and the instrumental evaluation of cytological and histological samples are also covered. The journal has a wide scope and aims to link scientists, clinical researchers and technicians through original articles, communications, editorials and commentaries, letters, reviews, announcements and news. Contributions should be clear, experimentally sound and novel.

3.2. Author guidelines (excerpt)

Manuscript format

Structure of original research article is a structured abstract; Introduction; Materials and Methods; Results; Discussion; Conclusion* Acknowledgements*; References; Tables*; List of figure captions*; List of supporting information legends*. or: Structured abstract; Content-specific headings; Acknowledgements*; References; Tables*; List of figure captions*; List of supporting information legends*. The Abstract should be divided into the following sections: ‘Background’, ‘Materials and Methods’, ‘Results’, ‘Conclusion’; it should not exceed 250 words.

Figures and tables

Tables should be self-contained and complement, not duplicate, information contained in the text. They should be supplied as editable files, not pasted as images, and should be numbered consecutively with Arabic numerals. Legends should be concise but comprehensive – the table, legend, and footnotes must be understandable without reference to the text. All abbreviations must be defined in footnotes. Footnote symbols: †, ‡, §, ¶, should be used (in that order) and *,

, * should be reserved for P-values. Statistical measures such as SD or SEM should be identified in the headings. Figure legends should be concise but comprehensive – the figure and its legend must be understandable without reference to the text. Include definitions of any symbols used and define/explain all abbreviations and units of measurement.

References

All references should be numbered consecutively in order of appearance and should be as complete as possible. In text citations should cite references in consecutive order using Arabic superscript numerals. For more information about AMA reference style please see the AMA Manual of Style. Sample references follow:

Journal article

1. Nedelec B, Forget NJ, Hurtibise T, et al. Skin characteristics: normative data for elasticity, erythema, melanin, and thickness at 16 different anatomical locations. Skin Res Technol 2016;22:263-275.

Book

2. Serup J, Jemec GBE, Grove G. Handbook of Non-invasive Methods and the Skin. Boca Raton, London, New York: CRC Press Taylor and Francis; 2006. 1029. Please note that journal title abbreviations should conform to the practices of Chemical Abstracts.

Internet document

3. US Food and Drug Administration. Labeling and Effectiveness Testing: Sunscreen Drug Products for Over-The-Counter Human Use — Small Entity Compliance Guide. https://www.fda.gov/drugs/guidancecomplianceregulatoryinformation/guidances/ucm330694.htm. Accessed June 16, 2017.

Article I: Subjective and objective skin colour of a farmworker group in the Limpopo Province, South Africa

Received: 4 December 2019 | Revised: 18 March 2020 | Accepted: 30 May 2020

DOI: 10.1111/srt.12895

ORIGINAL ARTICLE

WILEY

Subjective and objective skin colour of a farmworker group in the Limpopo Province, South Africa

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Funding information
CYW receives research funding from the South African Medical Research Council and the National Research Foundation (South Africa).The funders played no role in the study design, collection or analyses of data as well as the decision to publish or the preparation of the manuscript.

Abstract

Background: Farmworkers in the Limpopo Province, South Africa, are at risk of excessive exposure to solar ultraviolet radiation (sUVR) due to both their work and the sUVR environment in the geographic area. However, the natural protection provided by this group's skin against sUVR has not been quantified. The aim of this study was to evaluate the subjective and objective skin colour of a group of farmworkers in order to classify the natural photoprotection provided by melanin and to evaluate the different measurement methods.

Materials and Methods: Skin colour was established by using the subjective Fitzpatrick skin phototype system (FST) questionnaire and two objective methods, namely the individual typology angle (ITA°) and melanin index (MI). A total of 71 farmworkers participated in the study.

Results: Black Africans tended to perceive their skin to be lighter than objectively measured, potentially due to cultural factors. The constitutive skin colour of most farmworkers was objectively classified in the FST V/brown group. Significant differences were found between the ITA° and MI of sun-exposed (constitutive) and non–sun-exposed (facultative) skin in Black African and White farmworkers. A strong correlation was found between ITA° and MI on different anatomical positions indicating both methods are appropriate to determine skin colour in deeply pigmented skin.

Conclusion: The evaluation of skin colour with the use of both subjective and objective methods may be used to design an effective photoprotection programme for farmworkers in the Limpopo Province.

KEYWORDS
environmental health, farmworkers, individual typology angle, melanin index, skin colour, sun exposure

1 | INTRODUCTION

The natural protection provided by the skin against the potentially harmful effects of exposure to solar ultraviolet radiation (sUVR) is genetically determined. This photoprotection is mainly provided by melanin found in skin,[1] which acts as a protective barrier against sUVR reaching underlying structures of the skin including DNA.[2] The level of melanin does not necessarily stay constant after birth, with additional pigment synthesised in reaction to sUVR exposure to protect the skin.[3]

The genetically determined level of protective melanin in an individual's skin is referred to as constitutive skin while skin that is exposed to sUVR is referred to facultative skin.[4] Increased melanin content of skin provides increased photoprotection but not absolute protection.[5]

Damage to the DNA in the skin of individuals with elevated levels of melanin still occurs together with other negative health effects.[6] These health effects range from erythema to skin cancer.[7,8]

Several methods have been developed to classify skin in terms of the photoprotection it provides. These methods can be separated into subjective and objective methods.[9] The most often used subjective method is the Fitzpatrick skin phototype (FST) characterisation system.[10] This method uses self-report questions regarding the reaction of the skin to sUVR exposure and the development of freckles as well as questions on individual physical characteristics.[11] FST categories, I-VI, are defined based on constitutive characteristics pertaining to freckling, eye and hair colour as well as history of sunburn and tanning.[11] This method is easy to use which has added to its popularity.[12] However, it has been criticised as being prone to recall errors as well as subjected to the individual's own perception of their skin colour.[13,14] Some studies have also found that individuals with darker skin were confused by terminology such as tanning which resulted in the individuals providing incorrect information.[14,15]

Spectrometry has been found to be reliable in objectively measuring and classifying skin colour. However, the cost of equipment as well as training requirements may make this method impractical in some geographical locations.[9,14] Measurements of individual typology angle (ITA°) and melanin content represent these spectrometry methods.[14]

Environmental and behavioural factors influence the level of sUVR exposure of an individual.[16] Environmental factors include the higher ambient levels of sUVR found in geographical areas closer to the equator and at higher altitude.[17] The most northern province of South Africa, the Limpopo Province, has a latitude of 23.39°S to 22.15°S, and part of it falls in the area between the equator and the Tropic of Capricorn.[18] Behavioural factors include the posture of the individual carrying out a specific activity. Different occupations perform different activities, leading to different sUVR exposures.[19] In general, outdoor workers receive higher levels of exposure to sUVR than indoor workers due to extended periods of working outdoors in the sun.[20] Occupations classified as being at high risk of exposure to sUVR includes working in the agricultural sector.[21] Although farmworkers in South Africa are at high risk of sUVR exposure due to both the environmental and the behavioural factors mentioned, no study has been carried out to evaluate the natural photoprotection offered by the skin of this occupational group. Knowledge about the natural photoprotection of an occupational group can assist in the creation of customised photoprotection programmes. Although a study was carried out in an urban setting in South Africa on office workers to determine their skin colour, no study has been carried out in a rural setting at relatively high latitude and altitude in South Africa.[22]

This study aims to evaluate the subjective and objective skin colour of a group of farmworkers in the Limpopo Province of South Africa in order to classify the natural photoprotection of the farmworkers. The correlation of the subjective self-reported classification of skin colour and the two objective measurement methods is also reported.

2 | MATERIALS AND METHODS

2.1 | Study population

A total of 71 indoor and outdoor workers on an avocado and macadamia farm in the Soutpansberg mountains in the Limpopo province of South Africa were recruited (Figure 1). Ethical approval for the research study was provided by the North-West University Health Research Ethics Committee (ethics number: NWU-00101-17-A1). Data were collected after obtaining informed consent from the farmworkers.

2.2 | Subjective classification of skin colour

Demographic information was collected from farmworkers including the population group with whom they identified. Farmworkers completed a simple questionnaire that consisted of six questions to determine their skin colour using the Fitzpatrick skin phototype classification. The questionnaire was available in Afrikaans, English, Tshivenda or Sepedi by an interpreter. Terminology that was unclear to farmworkers was explained in the farmworkers' choice of these four languages. No questions were used that referred to "burning" or "tanning" of the skin as other studies have found that these questions proved problematic in an ethnic diverse population as they did not fit into the culture.[14,15] The questions asked farmworkers to classify the colour of their eyes and hair, how many freckles they have and to choose the picture with the skin colour closest to their own.

2.3 | Objective skin colour measurements

The individual typology angle (ITA°) and melanin index (MI) of the skin of farmworkers were measured using, a portable Courage + Khazaka Electronic GmbH Skin Colorimeter CL 400 WL and a Courage + Khazaka Electronic GmbH Mexameter® MX18, respectively. The instruments were calibrated and verified before measurements were taken. Measurements were taken in an indoor area where farmworkers could sit comfortably for 10-15 minutes before the measurements were taken. The skin colorimeter automatically calculated the ITA° from the measurements using the formula from Del Bino:

ITA° = (ArcTangent(L-50)/b) × (180/π) where π refers to the mathematical constant pi.

Skin colour was classified into the following categories using ITA°[23]:

Very light > 55° > Light > 41° > Intermediate > 28° > Tan > 10° > Brown > −30° > Dark.

The MI, the quantification of the amount of melanin in the skin, was measured with the Mexameter®. Skin was classified into an FST group according to this index using the classification system adapted from the manufacturer's manual. This adapted system was chosen as it was specifically tailored to the South African context.[15]

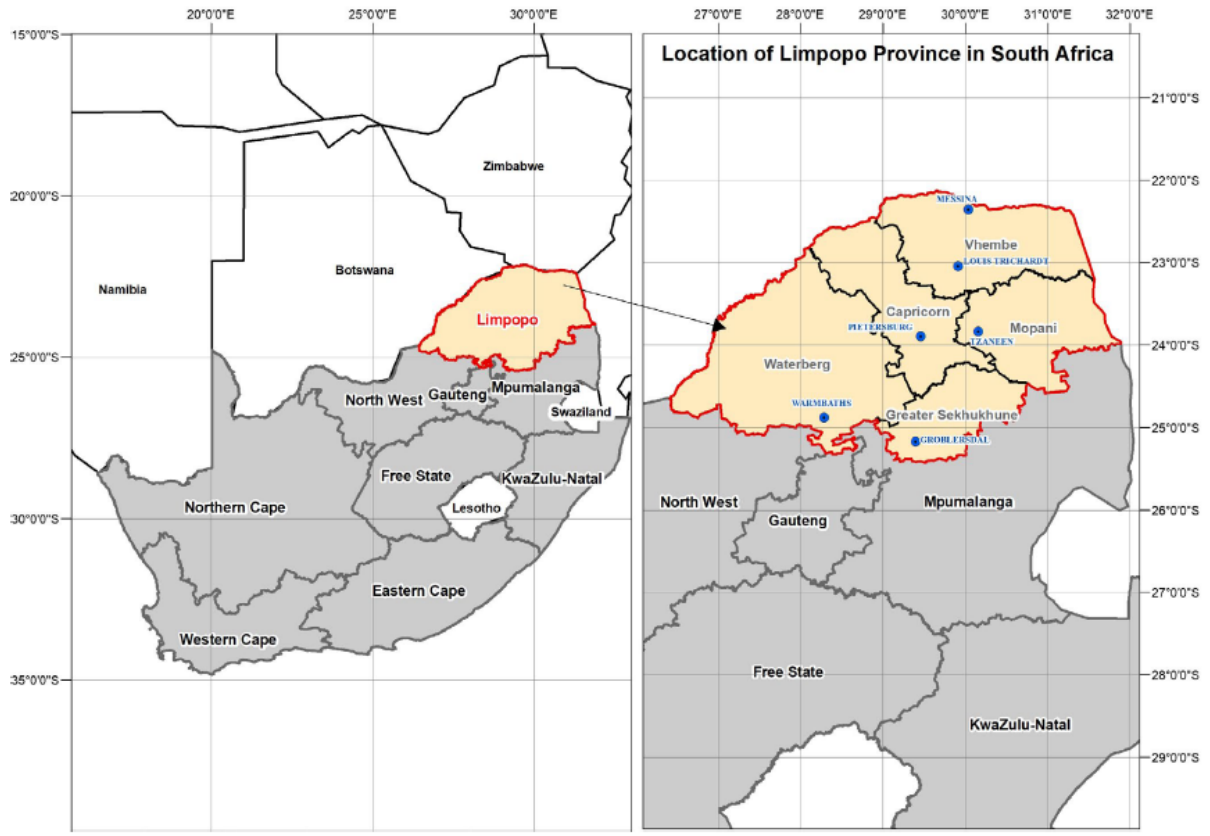

FIGURE 1 Location of the study site within South Africa [Colour figure can be viewed at wileyonlinelibrary.com]

FST I: 0-99.99; FST II: 100-149.9; FST III: 150-249.9; FST IV: 250-349.9; FST V: 350-749.9; FST VI: >750.

The back of the hand was chosen as the anatomical area that most accurately represented facultative skin colour while the inner upper arm was chosen to represent constitutive skin colour. The other anatomical positions were used to show distribution of skin colour. All anatomical positions measured are illustrated in Figure 2.

2.4 | Data analysis

SPSS statistical software was used to perform statistical analyses with statistical significance indicated by $P \leq .05$. Descriptive statistics were used to describe results. The independent *t* test was used to compare the means of ITA° or MI of the constitutive and facultative skin between the population groups, namely between Black African and White farmworkers as well between the outdoor and indoor farmworkers. The means of all the anatomical positions in a population were compared using a repeated measures ANOVA with a Greenhouse-Geisser correction and a Bonferroni post hoc test. The correlation between the ITA° and MI on an anatomical site was established using the non-parametric Spearman correlation.

3 | RESULTS

A total of 71 of the 74 farmworkers in the study were included in the analysis of the data. Of the 71 farmworkers, 22 (31%) were male and 49 (69%) were female. The farmworkers identified their population group as either Black African (86%) or White (14%) with no individual identifying themselves as Coloured (a South African population group term for individuals with mixed ancestry) or Indian/Asian. The farmworkers were also characterised as either outdoor or indoor farmworkers according to their job type.

There was also no statistical significant difference found between the ITA° ($F = 1.98$, $P = .17$) or MI ($F = 1.53$, $P = .20$) on the anatomical positions of the outdoor and indoor farmworkers. Therefore, the farmworkers were not evaluated further in terms of location of work/job type.

The self-reported FST, ITA° and MI classifications of the constitutive skin colour of Black African farmworkers are illustrated in Figure 3. The majority (62%) of Black African farmworkers reported their FST as either FST I, FST III or FST IV, and only 5% reported it as FST VI. The most common classification of constitutive skin using the ITA° classification was brown (52%). The MI classification system also showed the same distribution with FST V (52%) being the most common classification of constitutive skin. The 38% of Black African farmworkers who reported that their skin fell in either the FST V or

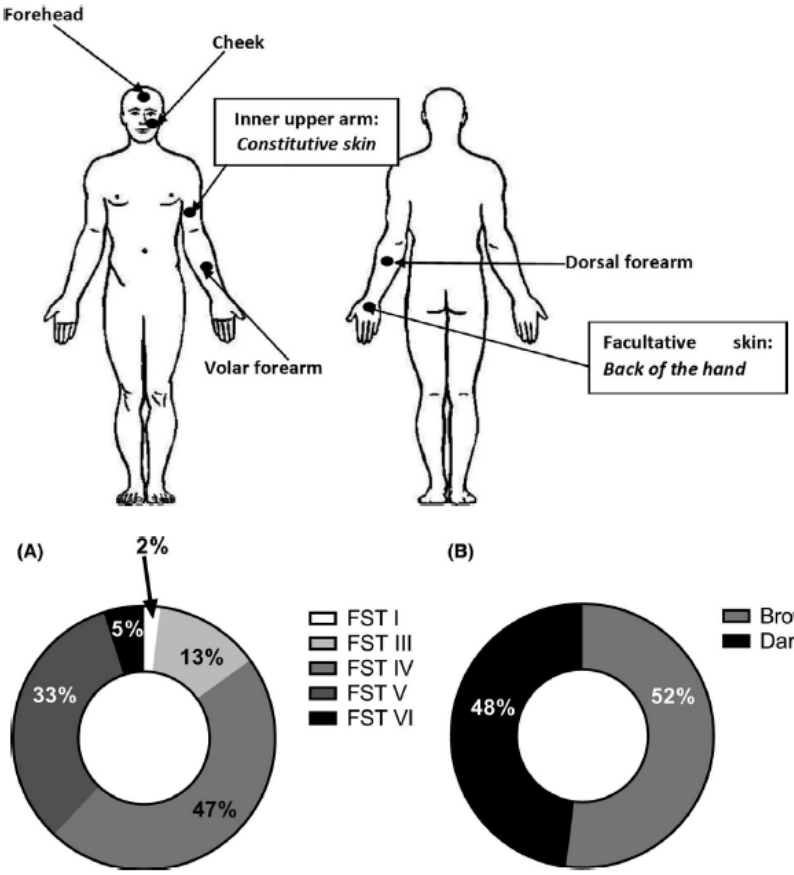

FIGURE 2 Location of different anatomical measurement positions (adapted from clipart from pervis-spann.com)

FIGURE 3 A, The self-reported (subjective), B, ITA° and C, MI classification of constitutive skin colour of Black African farmworkers

FST VI category was a lower percentage of the total Black African farmworker group than the 48% whose constitutive skin colour fell in either the brown or dark ITA° categories and the FST V or FST VI groups according to MI.

Most White farmworkers (70%) classified their skin as FST II which was consistent with the objective skin colour classification according to both MI and ITA° classification systems (Figure 4). White farmworkers' constitutive skin colour ranged from very light to intermediate according to the ITA classification and FST I to FST III according to the MI classification.

The ITA° values among the White farmworkers were higher than for Black Africans (F = 519.56, P = .00). Figure 5 shows that the highest mean ITA°, and therefore lightest coloured skin, in the Black African farmworker group was found on the inner upper arm which was chosen to represent constitutive skin. Of the remaining five anatomical positions, the lowest mean of ITA°, and thus darkest skin colour, was found on the back of the hand of Black African farmworkers which was chosen to represent facultative skin. The ITA° measured on anatomical positions in this farmworker group ranged from −66 to −5.

A repeated measures ANOVA with a Greenhouse-Geisser correction indicated that there were significant differences between the mean ITA° of the different anatomical positions (F = 56.21, P = .00). Post hoc tests using the Bonferroni correction showed that there were statistically significant differences in mean ITA° between the inner upper arm and the cheek (P = .00). The ITA° on the back of the hand and dorsal forearm differed significantly from each other and with all other anatomical positions in the Black African farmworker group (P = .00). Additionally, the forehead mean ITA° differed statistically significantly with that of the cheek (P = .04). The ITA° on the anatomical positions in the White farmworker group ranged from −32 to 69. The highest mean ITA° was also found on the inner upper arm of in this farmworker group while the lowest mean ITA° was found on dorsal forearm. The mean ITA° measured on the anatomical positions of the White farmworkers differed significantly (F = 9.75, P = .00). Statistically significant differences in ITA° were found between the inner upper arm and the back of the hand (P = .02), the cheek (P = .03) and dorsal forearm (P = .01).

The MI in the Black African farmworkers was generally higher than in White farmworkers (F = 370.75, P = .00). The mean MI provided in Figure 6 shows that the back of the hand was the anatomical site with the highest mean MI in the Black African group while the lowest MI and, thus, the lightest skin colour was found on the volar

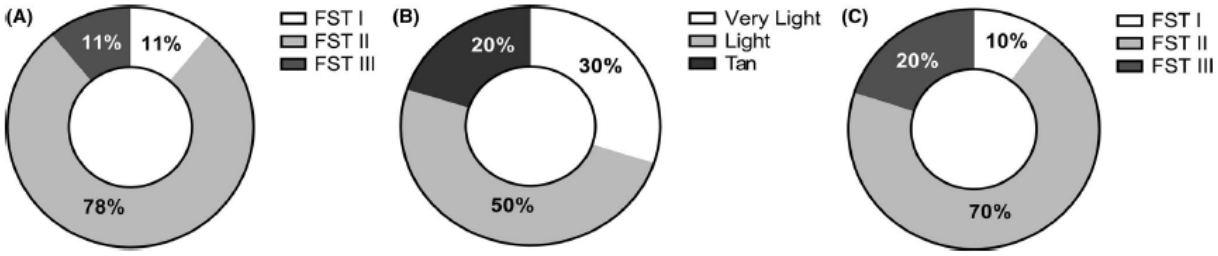

FIGURE 4 A, The self-reported (subjective), B, ITA° and C, MI classification of constitutive skin colour of White farmworkers

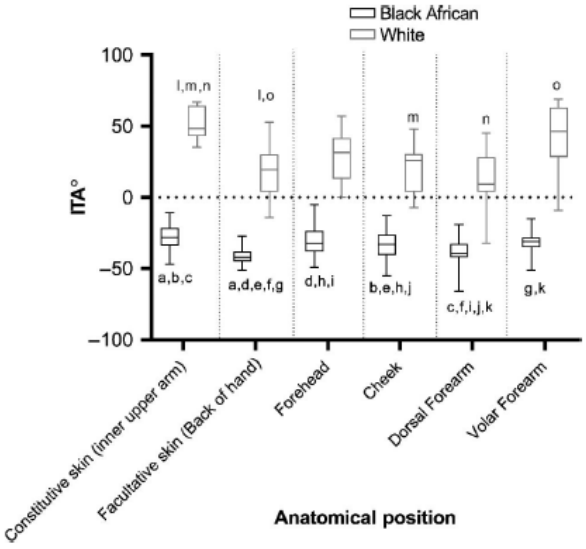

FIGURE 5 The statistically significant differences between ITA° values on anatomical positions of Black African and White farmworkers. The line in the middle of the box section of the graph indicates the mean ITA°. The box extends from the 25th to the 75th percentile with upper limit indicating the maximum ITA° and lower limit indicating the minimum ITA°. The alphabet letters indicate the anatomical positions as determined by repeated measures ANOVA

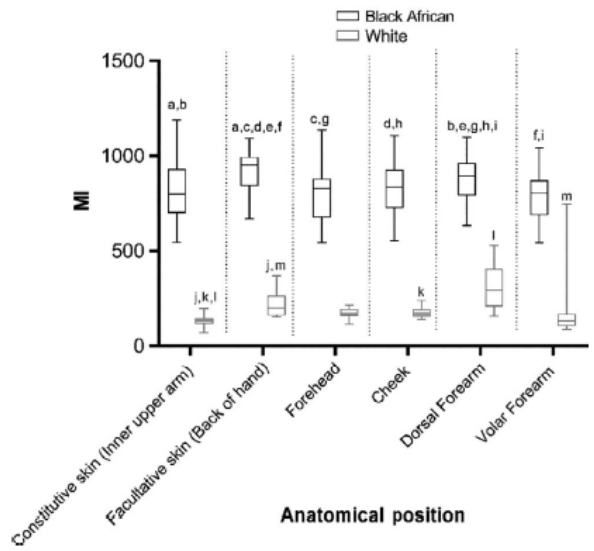

FIGURE 6 The statistically significant differences found between MI values on anatomical positions of Black African and White farmworkers. The line in the middle of the box section of the graph indicates the mean MI. The box extends from the 25th to the 75th percentile with upper limit indicating the maximum MI and lower limit indicating the minimum MI. The alphabet letters indicate the anatomical positions as determined by repeated measures ANOVA

forearm. The MI measured on the anatomical sites ranged from 499 to 1 188.

In the Black African group, the repeated measures ANOVA with Greenhouse-Geisser correction showed statistically significant differences between the mean MI of the different anatomical positions (F = 29.01, P = .00). Statistically significant differences were found when both the dorsal forearm and the back of the hand were compared to all the other anatomical positions including each other, with P = .00 except for the comparison between the mean of the dorsal forearm and inner upper arm when P = .01. The MI measured on the anatomical positions in the White farmworker group ranged from 70 to 529. The dorsal forearm was the anatomical site with the highest mean MI in White farmworkers while the lowest MI was found on the inner upper arm. The mean MI on the anatomical positions of the White farmworkers differed statistically significantly (F = 16.08, P = .00) (Figure 5). Significant differences were found for mean MI between the means of the dorsal forearm and the cheek (P = .04), volar forearm (P = .00) and inner upper arm (P = .04) as well as between the volar forearm and both the cheek (P = .01) and back of the hand (P = .00).

A statistically significant strong negative correlation was found between the self-reported FST and constitutive (inner upper arm) ITA° of the Black African farmworkers (p = −0.775, P = .000). However, no statistically significant correlation was found between the self-reported FST and constitutive (inner upper arm) ITA of White farmworkers (p = 0.229, P = .553). The correlation between the self-reported FST and constitutive MI of Black African farmworkers was weak but still statistically significant (p = 0.300, P = .020). No statistically significant correlation was found between self-reported FST and constitutive MI of White farmworkers (p = −0.504, P = .166).

The strong significant negative correlation between the ITA and MI on the facultative (back of the hand) and constitutive skin (inner upper arm) is illustrated for Black African farmworker in Figure 7. The same strong significant negative correlation was found in the White farmworkers (Figure 8).

4 | DISCUSSION

The unique demographic profile of workers in South Africa requires knowledge of the natural photoprotection of an occupational population to create an effective photoprotection programme for a specific workplace. The demographic profile of a workplace may influence the use of photoprotective measures that forms part of the programme and therefore its effectiveness.[24,25] This study found that more than 80% of the farmworkers identified themselves as Black African which is similar to the 2011 Census in which 97% of Limpopo province residents were Black African.[26]

Even though there was a correlation between the self-reported (subjective) FST and both the ITA° and the MI, most of the Black African farmworkers reported their skin colour being at least one FST category lighter than determined by objective measurements. It may be possible that some workers did not fully understand what was expected of them due to unfamiliar terms translated from English to Tshivenda or Sepedi. This potential confusion may explain the 15% of farmworkers that chose the FST I and FST II categories. However, it is unlikely that the 46% of workers who chose the FST IV category were confused when making their choice. This disparity between perceived and actual skin colour was also found in an urban South African work population which may indicate that it is a latent phenomenon that is not influenced by geographic area.[22] This tendency to consider their skin colour lighter than determined by objective measurements may be an interesting mirror reflection of the so-called "dark shift" phenomenon identified by other studies.[13] Where the "dark shift" phenomenon describes the overestimation of their skin melanin content by individuals with very fair skin, the current findings suggest that individuals with skin classified as brown or dark according to the ITA classification underestimated the melanin content of their skin. The perception that one's skin is lighter than it is in reality, may be due to the social norm that a lighter skin is more beautiful, illustrated by the popular practice of using skin lightening products by Black African women in South Africa.[27] Care should be taken that this underestimation of the skin melanin content of this occupational group does not lead to the perception that the use of photoprotection measures is unnecessary. It may only mean that the focus of a photoprotection programme needs to be shifted towards other photoprotective measures such as protection of the eyes.

The reason that no statistically significant differences were found between either the ITA° or MI of the anatomical positions of the outdoor and indoor farmworkers may be that the farmworkers are moved from one type of job to another according to what is needed on the farm as well as a high rate of seasonal workers. This means that a farmworker who is currently working as an indoor worker may have worked as an outdoor worker on the specific farm or another work site in the past, possibly recently. The variety in working conditions may have influenced their exposure to sUVR and, subsequently, their skin colour. The leisure activities of the outdoor and indoor farmworkers may also have been the same resulting in similar exposure to sUVR. These findings may indicate the ethnic group has a stronger effect on skin colour than job type on this specific occupational setting.

Both types of objective measurements of skin colour (ITA° and MI) determined that the constitutive skin colour of all Black African farmworkers fell in either the FST V/Brown or FST VI/Dark categories. This finding only partially agrees with previous research that found that the skin colour of most people born in South African falls in the range from FST I to V.[15,28] While the majority of the farmworkers' constitutive skin colour did fall in this range, approximately 40% were classified as FST VI/Dark. This slight disparity may be due to a unique genetic makeup of individuals living in the farm's geographic area in the North of South Africa.

The significant differences that were found when comparing the skin colour of the majority of anatomical positions in both population groups as well when comparing the melanin content of skin in the Black African farmworkers may be due to how these positions varied in their sUVR exposure. This variation was expected as it was also reported in previous research done in the general population.[22] The variations in the skin colour in this farmworker population may be related to the different orientations of anatomical positions resulting from the specific body postures required by an activity. The different orientation resulted in different amounts of sUVR falling on each anatomical site.[29] For example, while bending forward to water a young sapling, the cheek of the farmworker or farmer would be orientated mostly on the vertical plane and the sUVR possibly blocked by the head. In contrast, the dorsal forearm and back of the hand would be positioned on the horizontal plane and, therefore,

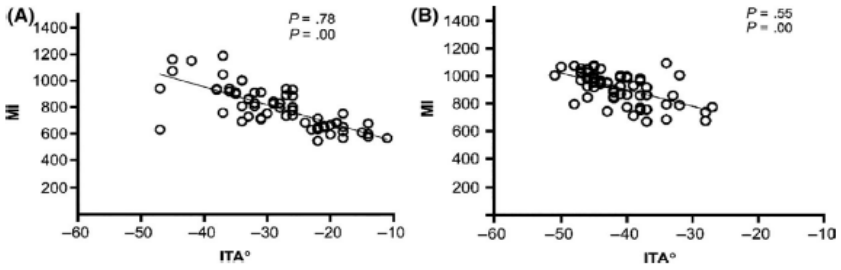

FIGURE 7 Correlation between the ITA° and MI in the Black African farmworker population group on the (A) constitutive skin (inner upper arm and (B) facultative skin (back of the hand)

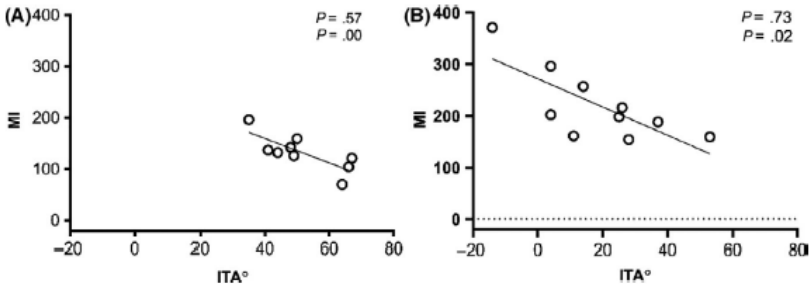

FIGURE 8 Correlation between the ITA° and MI in the White farmworker population group on the (A) constitutive skin (inner upper arm) and (B) facultative skin (back of the hand)

receive more sUVR. The type of crops with which the farmworker or farmer works has an influence on the type of body posture that is adopted and protective clothing worn.[30]

The significant difference found between the colour of the constitutive (inner upper arm) and facultative (back of the hand) skin may be explained by the reasons provided previously. Specifically, due to the reduced sUVR exposure of the inner upper arm caused by the wearing of shirts with sleeves and shielding of the inner upper arm by the arm structure. In contrast, the combination of the lack of wearing gloves by the farmworkers during work and the already mentioned orientation of the back of the hand may be the reason that this anatomical site was identified as having the darkest skin colour in the biggest population group namely Black African farmworkers. The significant difference between the constitutive (inner upper arm) and facultative skin (back of the hand) in the Black African population group (FST V to FST VI) was also found in the White population group (FST I to FST III). However, the small number of White farmworkers that participated in the study may have influenced the difference between constitutive and facultative skin in this population group.

A study that evaluated the mechanism of increased skin colour of individuals from different ethnic groups after irradiation with UVR found that the melanocyte density in Black skin was not elevated 7 days after irradiation took place.[31] This was in contrast to the melanocyte density in White and Asian skin which is slightly increased after the same time period.[31] Regardless, the evidence that farmworkers whose skin colour was classified as FST I to FST III had "tanned" to a greater extent than those farmworkers whose skin colour was classified as FST V or FST VI may indicate that the description that individuals in the darker FST categories (FST V and FST VI) "tanned profusely" is incorrect.[33] This flawed description of the tanning properties of the skin in these two phototypes may be that the first four original categories of the FST classification were determined using skin's clinical response to UVR exposure while the last two phototypes, that were added at a later stage, were determined using constitutive skin colour as well as ethnic classifications.[34] This finding may add to the growing argument for the expansion of the FST classification system by adding a category after FST VI to cater for the various skin types currently being grouped together in this last skin phototype category.

The strong significant correlations (all anatomical positions) between ITA° and MI resulted in the findings concurring with previous research that both objective measurements are suitable to determine skin colour in this type of population.[15] In addition, the ITA° skin colour categories have been found to correlate well with the MI FST categories, which further strengthens the finding that both systems may be used to objectively determine skin colour.[32] The choice of either of the two objective measurements of skin colour may make it easier to conduct these types of evaluations in rural areas where only one of the methods may be available. It is recommended that the adapted MI classification system, where the cut-off point of FST V was raised to 750, be used in a South African and possibly wider African context. Without the larger FST V classification group, the risk may arise that individuals with noticeably different skin colour are treated the same way when it comes to photoprotection.

This was the first study where the skin colour, and consequent natural photoprotection, of an agricultural occupational group was categorised in South Africa, specifically in the most northern province of the country. Several limitations of the study were identified. The first limitation was the small population of White farmworkers and the total lack of Coloured or Indian/Asian farmworkers due to the population demographic of the worker population on the farm. A larger sample would provide more accurate findings among White farmworkers as well as characterisation of the skin colour of the other two population groups. The second limitation is that it may not be possible to extrapolate this study's findings with regard to the profile of the skin colour and differences in the skin colour on the different anatomical positions to other farmworker populations in South Africa. This is due to the differences in the environmental and behavioural factors that influence workers' exposure to sUVR and, thus, their facultative skin colour. The genetic makeup of workers in other areas that influence their skin's response to sUVR may also be different. Similar studies should therefore be conducted in other occupations and geographical areas in South Africa. The third limitation is that the measurements were taken only during Summer. Facultative skin colour measurements may differ in other seasons as it is influenced by different sUVR levels received during these times. A follow-up study to determine whether facultative skin colour statistically differs in Winter would indicate whether the previously reported seasonal variability of facultative skin is also found in this specific occupational population. A follow-up study that extends over a few months will also indicate changes in skin colour and melanin content due to changes in work activities.

5 | CONCLUSION

An effective photoprotection programme will need to cater to all skin phototype groups so that most farmworkers feel that the programme is relevant to them. In addition, extensive assessment of any photoprotection programme will be needed during pre-implementation to ensure that cultural beliefs and behaviours are carefully taken into consideration. Although self-reported FST is an appropriate method of determining skin colour, the cultural influences on the perception by the workers of their own skin colour should be taken into account when using the information in formulating photoprotective measures for the population. Both objective methods to determine skin colour was found to be appropriate to use in this population. The variation of skin colour on different anatomical positions should be also be used to inform the type of photoprotective measures that needs be focused on in the workplace. Overall, the evaluation of skin colour with the use of different methods is a valuable tool in the design of a successful photoprotection programme.

ACKNOWLEDGEMENTS

We offer our heartfelt thanks to the following individuals for their help with the study, namely Ms Thandi Kapwata for the creation of the map of the study site and Ms Cynthia Ramotsehoa for assisting with training in the use of the instrumentation. We also thank the owner of the farm where the study was conducted for allowing us to perform the study on his property as well as all the farmworkers who participated in the study.

CONFLICT OF INTEREST

None of the authors had a conflict of interest.

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How to cite this article: Linde K, Wright CY, du Plessis JL. Subjective and objective skin colour of a farmworker group in the Limpopo Province, South Africa. *Skin Res Technol*. 2020;26:923–931. https://doi.org/10.1111/srt.12895

CHAPTER 4: ARTICLE II

Linde, K, Wright CY, Kapwata T, Du Plessis JL. (2020) Low use of ocular sun protection among agricultural workers in South Africa: need for further research. Submitted to *Photochemistry and Photobiology* to be considered for publication. Proof of submission of this Research Note is attached in Appendix B.

4.1. Instructions to authors

Photochemistry and Photobiology publishes peer-reviewed, original Research Articles, Rapid Communications, Research Notes, Technical Notes, Invited Perspective Articles, Method Articles and Invited Reviews. Topics span from Photochemistry, Photophysics and Phototechnology to Photosensory and Circadian Biology, Photosynthesis, Bio- and Chemiluminescence, Photomedicine, Photoprotection, Environmental Photobiology UV Effects and Vision. The editorial policy of the Journal is to publish manuscripts of the highest quality, combining scientific rigor, clarity, and brevity with rapid publication. To this end, all manuscripts are carefully reviewed by at least two independent specialists in the field and every effort is made to provide useful editorial assistance to authors.

4.2. Author guidelines

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Research Notes and Technical Notes should follow the outline of regular Research Articles but not exceed 4 printed journal pages. Articles include abstract, introduction, presentation of the results and a discussion section followed by the description of the methods. Double space manuscript, references list, tables and figure legends. Include page numbers and line numbering. Use italics for scientific names only. Boldface, italic, subscript and superscript word-processing commands should be retained. Footnotes should be avoided. If necessary, use standard footnote symbols in the order †, ‡, §, ||, ¶. Footnote the title only to show (a) that some or all of the material was presented at a meeting (give name, dates, and location of meeting), or (b) dedication of the paper. Current address of an author can be given in a footnote to the author's name. Every paper by two or more authors must have a footnote to one author's name: "*Corresponding author: e-mail address (name)" The superscript * is reserved to identify the corresponding author. Assemble the manuscript with a separate Title page. Section headings are: Abstract, Introduction, Materials and Methods, Results, Discussion, References, Tables, appendix if needed, and Figure Captions. The Results and Discussion sections may be combined. The section heading Conclusion is allowed but not required. Section headings are capitalized. Do not use paragraph numbering.

Figure and tables

All figures must be uploaded separately from the text, with the figure number indicated. Preferred formats are: EPS or PDF for line art or combination images, TIFF for photographic images. Office formats may be acceptable but the printed result cannot be guaranteed. Acceptable resolutions: line art or combination images should be saved at 600 dpi. Photographic images must have a resolution of 300 dpi at final size. Figure legends: Significant experimental details can be given, avoiding repetition of the text. Symbols and abbreviations in legends must agree with those in figures. Abbreviations must also agree with those in the text. Define error bars in figure legends. Tables should be prepared in Word or imported from Excel and contained in the text file, placed after the references. However, it was decided to include the tables in the text of the article for examination purposes of this thesis. To label tables, begin at left margin "Table 1." The caption follows immediately on the same line. Use the footnote symbols as described above, beginning with † on each table. If a table has more than six footnotes, double the symbols in sequence: ††, etc. Literature citations are given as in the text (a number in parentheses corresponding to the number in the Reference list).

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For reference citations in text, use numbers in parentheses in the order of appearance. The references should be listed at the end of the paper, in numerical order. Each citation must have a distinct number (no multiple references). The names of all authors should be given; do not use "*et al*." in the list of references.

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In Press:

Dewar, M. S. J. and W. Thiel (1997) Ground states of molecules. J. Am. Chem. Soc. (In press, DOI: XXXXX.xxxxxx)

Article II: Low use of ocular sun protection among agricultural workers in South Africa: need for further research

Low use of ocular sun protection among agricultural workers in South Africa: need for further research

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Running title: Ocular sun protection among farmworkers

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Word count: 899 words

ABSTRACT

Although ocular diseases related to solar ultraviolet radiation exposure have a high prevalence in Africa, little is known about the occupational use of ocular photoprotective measures on the continent. In a survey of South Africa farmworkers on a farm in the Limpopo Province, we analyzed factors related to ocular sun protection including use of different types of hats and sunglasses in relation to age, gender, and duration of agricultural employment. Majority of participants (80%) never wore sunglasses while 23% never wore a hat when working. More male workers used measures to protect their eyes than female workers. The type of hat most worn was a cap although broad-brimmed hats provide more effective photoprotection. The need for awareness campaigns that focus on the importance of using photoprotective measures in both an agricultural and South Africa context was identified.

INTRODUCTION

Excess exposure to solar ultraviolet radiation (UVR) has been linked to increased risk of developing pterygium (1), age-related cataracts (2) and especially cortical cataracts (3) regardless of skin colour (4). Photoprotective measures promoted to protect the eye include wearing hats and sunglasses (5). Sub-Saharan-Africa has a high incidence of ocular diseases such as cataracts and, therefore, ocular sun protection should occur (6). However, most studies that assessed ocular photoprotective measures of outdoor workers occurred outside of Africa (7,8,9). Therefore, we established the use of ocular photoprotection by outdoor farmworkers on a macadamia nut and avocado farm in the Limpopo Province, South Africa (Ethics Approval NWU-00101-17-A1).

MATERIALS AND METHODS

Outdoor workers self-completed questions regarding their use of hats, type of hat and sunglasses during working hours. Responses were treated as dichotomous variables ('wear a hat during work' was either yes or no; 'wear sunglasses during work' was either yes or no'). Demographic variables (gender was either male or female) were treated similarly. Age was grouped in tens from 20 - 29 years etc.; duration of agricultural employment was < 5 years, 5-10 years, 11-20 years > 20 years. Type of hat was categorical and hat types were grouped in terms ocular protection offered, i.e., broad-brimmed hats that offer the most protection, then cap and lastly visor. The chi-square test of association was used to assess relationships between study participant characteristics and use of ocular sun protection measures.

RESULTS

Majority of participants recruited were adults aged 24 to 40 years (58%) (Table 1). Most workers were employed for ten years or less (91%). Ocular protection was slightly higher among men than females for sunglasses use. In addition, more males than females wore a hat with a brim. A

significant association was found between gender and the practise of using direct ocular protection (i.e., sunglasses) while working ($p < 0.01$). None of the females working outdoors reported protecting their eyes in this manner, however, 33% of males did do so (Table 2a). Overall, only 30% of sampled respondents wore broad-brimmed hats while an additional 40% preferred caps and visors. A higher percentage of females (44%) compared to males (19%) wore broad-brimmed hats which offer more ocular protection that caps and visors (Table 2b).

Table 1. Characteristics of study participants Total N=43.

Category	Variable	Frequency n	Frequency %
Sample description	**Gender**		
	Male	24	56
	Female	19	44
	Age		
	24 - 30 years	10	23
	31 - 40 years	15	35
	41 - 50 years	3	7
	> 50 years	15	35
	Duration of agricultural employment		
	< 5 years	21	49
	5 - 10 years	18	42
	11 - 20 years	1	2
	> 20 years	3	7
Ocular sun protection	**Hat used at work**		
	Never	1	23
	Sometimes	7	16
	Always	26	61
	Main type of hat worn at work		
	Beanie	9	21
	Beanie and cap over beanie	3	7
	Visor	2	5
	Cap	12	28
	Broad-brimmed hat	3	7
	Broad brimmed hat over beanie	8	19
	Broad brimmed hat and / or cap	1	2
	Broad brimmed hat over doek	1	2
	Sunglasses used at work		
	Never	34	80
	Sometimes	8	20
	Always	0	0

Table 2. Association between study participant characteristics and use of ocular sun protection

(a) Direct ocular protection

Variable		Protect eyes when working (n)			
		Never	Sometimes	Total	p-value
Gender	Female	18	0	18	0.006
	Male	16	8	24	
Age group	24-30 years	8	2	10	0.603
	31-40 years	13	2	15	
	41-50 years	3	0	3	
	>50 years	10	4	14	

(b) Indirect ocular protection

Variable		What type of hat do you wear (n)				
		Broad brimmed hat	Cap	Visor	Total	p-value
Gender	Female	8	10	0	18	0.127
	Male	4	15	2	21	
Age group	24-30 years	1	9	0	10	0.129
	31-40 years	6	6	0	12	
	41-50 years	0	3	0	3	
	>50 years	5	7	2	14	

DISCUSSION

The study shows poor use of sunglasses that provide direct ocular protection when working, amongst this sample of South African outdoor farmworkers, especially among females. This is of concern as the prevalence of cataracts in this geographic area is estimated to be ~ 44% (10). The relatively high cost of sunglasses may be part of the reason why their use is not common in this population; as well as the low levels of knowledge regarding the health benefits of wearing sunglasses. Sunglasses that limit UVR and fit close to the face have been shown to help protect individual's ocular health (11).

Most outdoor workers preferred to wear caps and visors rather than broad-brimmed hats while working outside. Broad-brimmed hats provide a higher degree of complete facial photoprotection than hats with smaller brims such as caps (12). Fashion trends and cost play an important part in the choice of hat (13). Current fashion lends itself more to wearing caps than broad-brimmed hats, in occupational and recreational settings, which has also been noted in other countries, e.g., New Zealand (13).

CONCLUSION

Determining use of photoprotective measures in a South African occupational setting such as a farm assists in identifying potential health risks posed to outdoor workers. Similar research in different geographical areas in South Africa as well as different occupations will be important to provide a comprehensive picture of photoprotection use and to inform sun protection awareness campaigns

Implementing targeted awareness campaigns is necessary to educate outdoor farmworkers on the need to use appropriate measures to protect their eyes while working. These types of

campaigns need to form part of a comprehensive photoprotection plan that also considers the socio-economic barriers that may hinder the use of these measures in agricultural workplaces such as farms. Focusing on ocular health in occupational settings may aid in the effort to address the burden placed by ocular diseases on health systems in Africa.

Acknowledgements: We thank Mr. M Sebola for translation of the questionnaire and Ms. AT Govhola for interpretation work.

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CHAPTER 5: ARTICLE III

Linde K, Wright CY, Du Plessis JL. 2020. Ultraviolet radiation protection factor of clothing: South African farmworkers on a macadamia nut and avocado farm. Submitted to *Annals of Work Exposure and Health* to be considered for publication. Proof of the submission of this Short Communication is attached in Appendix B.

5.1. Instructions to authors

Annals of Work Exposures and Health is dedicated to presenting advances in exposure science supporting the recognition, quantification, and control of exposures at work, and epidemiological studies on their effects on human health and well-being. A key question we apply to submission is, "Is this paper going to help readers better understand, quantify, and control conditions at work that adversely or positively affect health and well-being?"
We are interested in high quality scientific research addressing:

- the quantification of work exposures, including chemical, biological, physical, biomechanical, and psychosocial, and the elements of work organization giving rise to such exposures;
- the relationship between these exposures and the acute and chronic health consequences for those exposed and their families and communities;
- populations at special risk of work-related exposures including women, under-represented minorities, immigrants, and other vulnerable groups such as temporary, contingent and informal sector workers;
- the effectiveness of interventions addressing exposure and risk including production technologies, work process engineering, and personal protective systems;
- policies and management approaches to reduce risk and improve health and well-being among workers, their families or communities;
- methodologies and mechanisms that underlie the quantification and/or control of exposure and risk.

5.2. Authors guidelines

Manuscript format

Short communications are descriptive studies, with limited data, that present new information of importance to the readership, but with insufficient data for a full original research report. Examples include: a description of an occupational disease case with a thorough investigation

of the exposures likely to have given rise to the disease; a demonstration of a new measurement principle or device with potential for solving an important exposure measurement problem; evidence demonstrating the effectiveness of a novel exposure control strategy. In each case, the data available are insufficient to support a full original research paper or prove the validity of the observation, but provide potentially important information to occupational hygienists. Short communications will generally be less than 1500 words and have up to two tables or figures. Such reports will be peer reviewed through our normal process

Figures and tables

Tables should be numbered consecutively and given a suitable caption. As with Figures, it is helpful to incorporate them into the text of the first submission, but in the revised version each table should be presented on a separate page. Footnotes to tables should be provided below the table and should be referred to by superscript lowercase letters.

References

References should only be included which are essential to the development of an argument or hypothesis, or which describe methods for which the original account is too long to be reproduced. References in the text should be in the form Jones (1995), or Jones and Brown (1995), or Jones et al. (1995) if there are more than two authors, and they should be incorporated naturally into the text. For example: Jones and Brown (1995) and Hospath et al (2006) observed total breakdown of control..., or Total breakdown of control has sometimes been observed (Jones and Brown, 1995; Hospath et al., 2006).

Papers whose references are not properly arranged may be returned for revision without review.

At the end of the paper, references should be listed in alphabetical order by name of first author, using the Vancouver Style of abbreviation and punctuation. ISBNs should be given for books and other publications where appropriate. Material unobtainable by readers should not be cited. Personal Communications, if essential, should be cited in the text (e.g., Professor O.H. Poobah, Institute for Dusty Sciences). Internet material can be referred to if it is likely to be permanently available; the date on which it was last accessed should be given. References will not be checked editorially, and their accuracy is the responsibility of authors.

Examples:

Simpson AT, Groves JA, Unwin J, Piney M. (2000) Mineral oil metal working fluids (MWFs)—

Development of practical criteria for mist sampling. Ann Occup Hyg; 44: 165–72.
Vincent JH. (1989) Aerosol sampling: science and practice. Chichester, UK: John Wiley. ISBN 0 471 92175 0.
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Morse SS. (1995) Factors in the emergence of infectious diseases. Emerg Infect Dis [serial online] 1995 Jan–Mar;1(1). Available from: URL: http://www.cdc.gov/ncidod/ EID/eid.htm (accessed 25 Oct 2010)

Article III: Ultraviolet radiation protection factor of clothing: South African farmworkers on a macadamia nut and avocado farm

Ultraviolet radiation protection factor of clothing: South African farmworkers on a macadamia nut and avocado farm

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ABSTRACT

Clothing is a frequently used photoprotective measure. However, not all clothing provides the same level of protection. The ultraviolet protection factor (UPF) is used to quantify the protection provided by clothing against solar ultraviolet radiation (UVR). Polysulphone badges were placed underneath and on the outside of clothing worn by farmworkers on a macadamia nut and avocado farm in the Limpopo Province, South Africa during three seasons. The protection provided by the clothing was established by calculating the percentage of solar UVR that reached the skin underneath the clothing. No statistically significant differences were found between the percentage of solar UVR transmitted through clothing between different seasons although statistically significant differences were found between both the solar UVR underneath and on the outside of the clothing measured in different seasons. Only 5% of the clothing did not provide the minimum required protection against solar UVR, with almost 82% providing excellent protection. More than 75% of farmworkers reported removing their long sleeve overall jackets during the day and the short sleeve t-shirt worn underneath, however, did not cover 75% of the arm as required. Guidelines that are customized to the South African agricultural setting may be a useful tool in preventing excessive exposure to solar UVR in this sector.

Importance of research

This is the first study to our knowledge that quantified the protection provided by clothing worn by farmers or farmworkers to solar UVR using chemical dosimetry. Agricultural workers such as farmers and farmworkers are at high risk of exposure to solar UVR. Wearing long sleeved clothing is a common photoprotective measure used to reduced their exposure to solar UVR. However, the success of this photoprotective measure is determined by the ability of the fabric that the clothing is made of to prevent solar UVR from the reaching the skin underneath. The findings of this study may contribute to the process of formulating guidelines on the type of clothing that should be worn by farmers and farmworkers to protect themselves against excessive exposure to solar UVR.

INTRODUCTION

The solar ultraviolet radiation (UVR) that outdoor workers such as farmworkers are exposed to during their work activities may pose a risk to their health (ICNIRP, 2010). Clothing has been reported as being the most common photoprotective measure used by outdoor workers (Majumdar et al., 2016).

The level of protection provided by a piece of clothing is dependent factors such as the thickness of the fabric (Ghazi et al, 2014), the addition of UVR absorbers (Kan and Au), the colour of the fabric and the chemical processes that the fabric is subjected to during the manufacturing process (Jansen et al., 2013) as well as style and cut of clothing (King et al., 2018). There are three ways that fabric may react to UVR exposure namely transmission, reflection, or absorption. Transmission of UVR occurs when UVR passes through the gaps between the fibers of the fabric. During reflection of UVR by fibers of the fabric, the solar UVR is scattered while any UVR that is absorbed by the fabric fibers is converted to a different energy (Stankovic et al., 2009)

The photoprotective capacity of clothing is expressed using the ultraviolet radiation protection factor (UPF), which can be defined as the “ratio of erythemally effective solar UVR exposure on exposed skin to that received through the fabric” (ICNIRP, 2010). *In vitro* and *in vivo* methods can be used to calculate the UPF of clothing. The *in vitro* method consists of spectrophotometry (Urbas et al., 2012). An *in vivo* method that incorporates UVR dosimetry (electronic, chemical and biological dosimetry) is also available (Gambichler et al., 2002). Regardless of the differences between the *in vivo* and *in vitro* methods, there is a good correlation between them in calculating the UPF of clothing (Urbas et al., 2012).

Currently in South African, CANSA provides a “seal of recognition” for products such as UVR protective garments which require that clothing provide a UPF of 30 or higher and covers as much skin as possible (CANSA, 2019).
The aim of this study was to establish the solar UVR protection provided by the clothing worn by farmworkers on a macadamia nut and avocado farm in the Limpopo Province, South Africa using chemical dosimetry during three seasons.

METHOD

A total of 38 outdoor workers from a macadamia nut and avocado farm (Limpopo Province, South Africa) were recruited to participate in the study. Ethical approval for the study was provided by the North-West University Health Research Ethics Committee (ethics number: NWU-00101-17-

A1). A total of 91 measurements were taken over three seasons, namely autumn, spring and summer.

Polysulphone (PSF) badges (Manchester University UV group) were used to measure solar UVR on the outside and inside of farmworkers' clothing. Surgical adhesive tape was used to place a PSF badge on the shoulder of a farmworker, directly on the skin while another PSF badge was placed on the same shoulder on the outside of the clothing. Care was taken that the second PSF was not placed directly on top of the first PSF to prevent it blocking solar UVR from being transmitted through the clothing.

A spectrophotometer (DLAB SP-UV1000, France) was used to quantify the change in absorbance of the PSF badges at a wavelength of 330 nm. A calibration curve was created by calibrating the response of the PSF badges against the sun as source of UVR. The solar UVR levels in J/m^2 was converted to standard erythemal dose (SED) which is the standardized biologically weighted unit for the erythemal action spectrum with 100 J/m^2 equal to 1 SED (EN14255-3; Geiss et al., 2003). The amount of solar UVR that was transmitted through fabric of clothing was calculated using the following formula:

$$\% \text{ solar UVR transmitted through clothing} = (SED_{outside} / SED_{underneath})*100$$

Farmworkers also completed a questionnaire regarding the clothing they wore during work. The questionnaire was modelled on the questionnaire created by Salas *et al*. (2005) with some questions adapted to fit a South African agricultural setting.

Data analysis

Descriptive statistics was used to describe the solar UVR measured on the outside of the clothing and the inside of the clothing as well as the percentage of solar UVR that was transmitted through the clothing. A paired sample t-test was used to compare the solar UVR measured on the outside of the clothing with the solar UVR measured underneath clothing during a season. One-way analyses of variance (ANOVAs) were used to compare the mean SED measured on both the outside of the clothing as well as underneath the clothing the percentages of solar UVR transmitted through the fabric of the clothing between the different seasons. The percentage of solar UVR that could travel through the clothing was also compared with the Australian and New Zealand standard (AS/NZS 4399:2017) (SunSmart, 2018). The standard AS/NZS 4399:2017 was used because there is currently no legally binding South African standard regarding sun protective clothing.

RESULTS

Type of clothing worn by outdoor farmworkers

Farmworkers were provided by their employers with thick cotton long sleeve collared overall jackets and trousers as well as a short sleeve t-shirt. The short sleeve t-shirts covered approximately 50% of the outdoor workers' arms. A total of 51% (n= 19) of outdoor workers reported that they wore the long sleeve overalls every shift while an additional 41% (n=16) reported that they either wore the long sleeve overall jacket with the overall trousers or the overall trousers with only a short sleeve t-shirt. It was observed that some outdoor farmworkers removed their overall jackets during lunch on days when the weather was warm. Seventy-nine percent (n= 30) of the outdoor workers indicated that they removed their long sleeve overall jacket at some time during their shifts. Seasonal farmworkers were not provided with work clothing and usually wore self-provided short sleeve t-shirts and long trousers.

Solar UVR measured on and underneath the clothing

Figure 1 shows the means solar UVR measured outside and underneath the clothing worn by outdoor farmworkers during the three seasons. Statistically significant differences were found between both the solar UVR measured outside clothing ($F=7.33$, $p \leq 0.01$) and underneath clothing ($F=4.56$, $p=0.01$) when comparing the different seasons. Statistically significant differences were found between the SED measured on the outside of the clothing and underneath clothing during autumn ($p \leq 0.00$), spring ($p \leq 0.00$) and summer ($p \leq 0.00$).

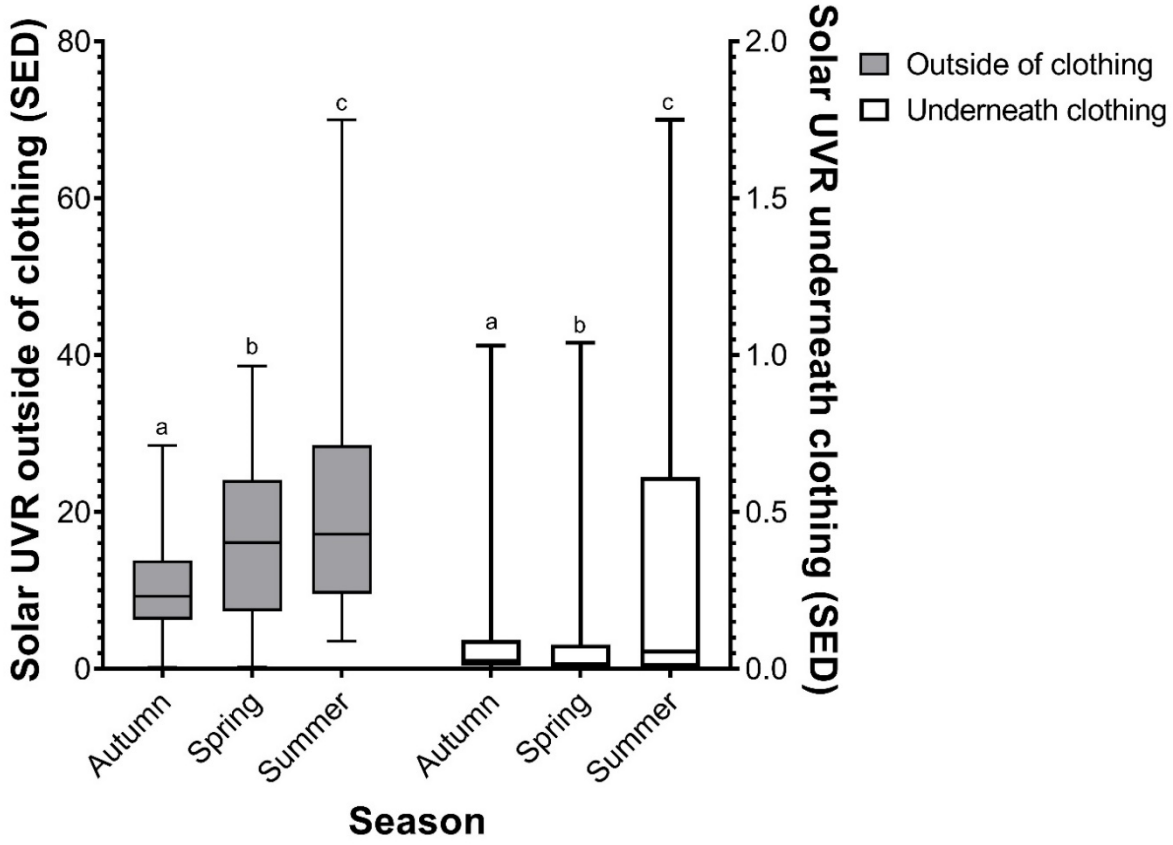

Figure 1. SED measured outside and underneath clothing

Percentage of solar UVR transmitted through clothing

The mean percentage of solar UVR that was transmitted through the clothing of outdoor workers per season is illustrated in Figure 2. No statistically significant difference was found between the percentage of UVR transmitted between the different seasons ($F=0.52$, $p=0.60$). Eighty-two percent of clothing could be classified as providing excellent protection, 4% good protection and 8% providing the minimum required protection against solar UVR. Only 6% of clothing provided less than minimum protection.

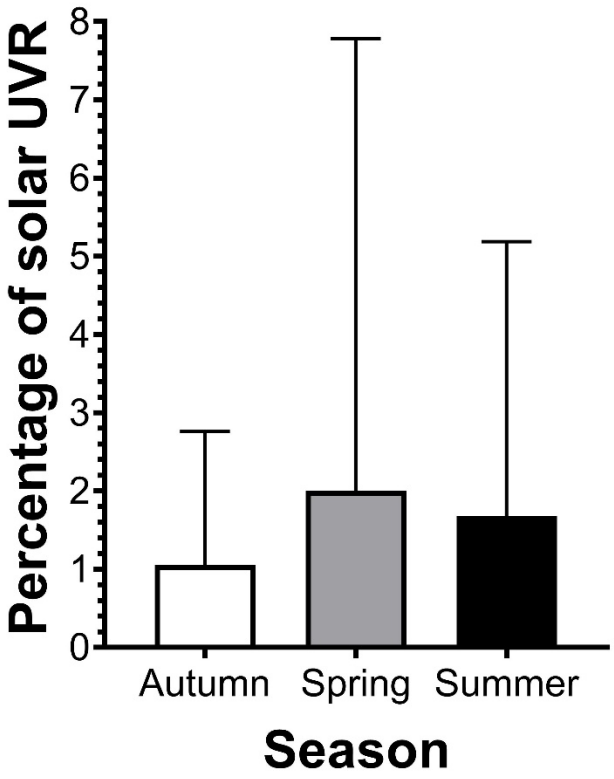

Figure 2. Percentage of solar UVR transmitted through clothing

DISCUSSION

The levels of solar UVR that farmworkers were exposed to both outside and underneath their clothing differed significantly when the values measured during the three seasons were compared which can be attributed to the seasonal differences in ambient solar UVR. The solar UVR measured on the outside of clothing differed significantly from the solar UVR measured underneath the clothing during all three seasons which may indicate that the clothing was blocking solar UVR from being transmitted through to the skin underneath. In addition, the percentage of solar UVR that was transmitted through the fabric of the clothing did not differ significantly between the three seasons. This may indicate that the level of solar UVR transmitted through fabric is not influenced by the season.

Most of the clothing evaluated could be classified as providing excellent photoprotection. The cases where the clothing did not provide sufficient protection may be due to farmworkers wearing their own clothing (among those who were not provided with clothing by the employer or that they preferred wearing their own clothing). Alternatively, the position adopted by farmworker to carry out their work duties may have led to increased solar UVR exposure of the skin.

Although most of the clothing did not allow high levels of solar UVR to be transmitted through the fabric, the style of and cut of the clothing worn did not in some instances cover the required amount of skin as specified by AS/NZS 4399:2017 (King et al., 2018). Most farmworkers reported that they removed their long-sleeve overall jackets during warm weather in spring and summer which exposed more skin to solar UVR. They, therefore, spent at least a portion of the workday working in the sun wearing only a t-shirt that did not cover at least 75% of their arms and a portion of their neck as required.

Guidelines for the type of clothing that should protect workers in the agricultural sector in South Africa against excessive exposure to solar UVR should be developed. These type of guidelines will aid employers in protecting their workers against negative health effects associated with solar UVR.

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CHAPTER 6: ARTICLE IV

Linde K, Wright CY, Du Plessis JL. (2020) Personal solar ultraviolet radiation exposure of farmworkers: seasonal and anatomical differences suggest prevention measures are required. Submitted to *Annals of Work Exposure and Health* to be considered for publication. Proof of the submission of this Research Article is attached in Appendix B.

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- the relationship between these exposures and the acute and chronic health consequences for those exposed and their families and communities;
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- the effectiveness of interventions addressing exposure and risk including production technologies, work process engineering, and personal protective systems;
- policies and management approaches to reduce risk and improve health and well-being among workers, their families or communities;
- methodologies and mechanisms that underlie the quantification and/or control of exposure and risk.

6.2. Authors guidelines

Manuscript format

Original research papers are reports of scientific investigations of matters affecting occupational risks, exposures, and methods of their assessment. Original research reports may be descriptive, observational and/or experimental investigations, and can usually be

presented as hypothesis-driven research. Original research reports should be able to clearly state their aim, define the methods with which evidence is gathered and organized, describe the analytic methods used, and present the results of these analyses in a transparent and interpretable format. The conclusions of the paper must be supported by the data and their analysis. Original research papers are normally under 4000 words with a maximum of 5000, and have up to six tables or figures. Original research papers are peer reviewed through our normal process. Please refer to Chapter 4 for the guidelines for figures, tables and references.

Article IV: Personal solar ultraviolet radiation exposure of farmworkers: seasonal and anatomical differences suggest prevention measures are required

Personal solar ultraviolet radiation exposure of farmworkers: seasonal and anatomical differences suggest prevention measures are required

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Abstract

Introduction Farmworkers are at risk of excess exposure to solar ultraviolet radiation (UVR) during their work activities, especially if they work in geographical areas with high ambient solar UVR levels such as in South Africa. Excess exposure to solar UVR may lead to several negative health effects such as certain cataracts and skin cancer. This study evaluated personal solar UVR exposure of a group of farmworkers to determine if they were at risk of related-health problems due to excess solar UVR exposure. **Methods** Polysulphone film (PSF) badges were placed on the shoulder, arm and top of the head of outdoor and indoor farmworkers on a macadamia nut and avocado farm in the Limpopo province for the duration of their daily work shift to evaluate their total daily solar UVR exposure. Sixteen days were assessed for each of the three, high solar UVR seasons, i.e., autumn, spring, and summer. **Results** Farmworkers' arms received the highest solar UVR exposures during autumn (Geometric Mean (GM) = 7.8 SED, where 1 standard erythemal dose (SED) = 100 J/m^2 , CI 95% 6.1 - 9.8 SED) while the highest exposures were on the top of the head both during spring (GM = 11.6 SED, CI 95% 7.3 - 17.4 SED) and summer (GM = 13.9, CI95% 10.4 - 17.9 SED). Statistically significant differences in solar UVR exposure were found between the body sites

during spring and summer but not autumn. The solar UVR exposure levels measured on the farmworkers' body sites exceeded the daily International Commission of Illumination (CIE) Occupational Exposure Limit of 1.3 SED for more than 80% of measurements during every season. **Conclusions** The relatively high daily solar UVR exposure levels of farmworkers suggest this occupational group is at risk of excess solar UVR exposure and preventive measures with awareness information to safeguard health is necessary for employers and employees.

Keywords: agricultural workers, environmental health, ultraviolet radiation occupational exposure, South Africa.

Importance of research

This is the first study to our knowledge to evaluate the personal solar UVR exposure of farmworkers on the African continent. Farmers and farmworkers have been identified as being of high risk of exposure to solar UVR. This is a concern as the ambient UVR levels in many African countries such as South Africa are high. This study quantified the personal exposure of this high-risk occupational group and enables employers to implement appropriate photoprotective measures to safeguard worker health. Summer is seen as the season in which outdoor workers are at the highest risk of exposure to solar UVR, however it may not be possible to assume that their exposure during other seasons such as autumn and spring complies with recommended solar UVR exposure limits. The evaluation of the seasonal personal solar UVR exposure of the outdoor farmworkers in our study can be used to determine if the use of photoprotective measures are needed in not just summer, but also autumn and spring by the workers. The solar UVR received by different body sites while working is influenced by the body's posture. To our knowledge, our study is one of the few studies that looked at the solar UVR exposure on different body sites during a range of different work activities found on a farm.

Introduction

Outdoor workers such as farmworkers are at high risk of exposure to levels of solar ultraviolet radiation (UVR) above the recommended exposure limit due to the long periods of time spent in the sun (ICNIRP, 2010). Excess exposure to solar UVR may lead to different skin cancers, development of certain cataracts and systemic effects such as reduced immunity (Ivanov et al, 2017; Bernard *et al*., 2019). Individuals with darker skin may have a higher melanocytic protection against health effects related to solar UVR skin exposure but this natural protection can be overwhelmed by exposure to high levels of solar UVR, although the mechanisms remain unclear (Greinert *et al*., 2015). In addition, they are still vulnerable to the effects related to solar UVR exposure of the eyes (Agbai *et al*., 2014)). The link between exposure to solar UVR and skin cancer in individuals with darker skin has been debated with most research finding no link between solar UVR exposure and melanoma. Further epidemiology and laboratory research may be needed (Liu *et al*., 2016).

Therefore, at this stage, prevention of the above-mentioned adverse health effects remains essential in individuals of all skin types. Understanding exposure levels is key, hence several methods have been developed to evaluate the personal exposure of individuals who may be exposed to excess solar UVR (King *et al*., 2015) rather than using ambient solar UVR levels as a proxy for personal exposure given differences in occupational, behavioural and anatomical factors that influence personal solar UVR exposure (Casale *et al*., 2015; King *et al*., 2015). For example, body posture assumed while in the sun may be determined by work demands related to the crop type on a farm, e.g. bending low or reaching high up (Salas *et al*., 2005; Nardini *et al*., 2014). In an occupational environment, the type of work influences the body posture and the length of time spent in the sun making it necessary to assess the personal solar UVR exposure of different types of occupations, including farm work (Schmalwieser *et al*., 2010).

Research studies conducted in several Europe countries, i.e., Austria, Denmark, Poland, Spain and Italy (Schmalwieser *et al*., 2010; Siani *et al*, 2011; Bodekær *et al*., 2015) investigated personal solar UVR exposure of agricultural workers (including farmers, farmworkers and vineyard workers etc.) using personal dosimetry. Although some of the studies used different measurement methods and included different types of agricultural activities, all of them found that agricultural workers' exposure exceeded the exposure limits recommended either by the American Conference of Governmental Industrial Hygienist (ACGIH) (0.3 SED) or the International Commission of Illumination (CIE) (1.0 to 1.3 SED)

(ICNIRP, 2010; Schmalwieser *et al*., 2010; Siani *et al*, 2011; Bodekær *et al*., 2015; ACGIH, 2020).

There is a lack of knowledge regarding the solar UVR exposure of outdoor workers and specifically farmworkers on the African continent including in South Africa (Lucas *et al*., 2016). To our knowledge, no such study to assess personal solar UVR of farmworkers has been conducted in Africa. This lack of knowledge is of concern as agriculture is a major occupational sector in both South Africa and the rest of Africa (STATSSA, 2020; Cristiaensen and Demery, 2018). Excess solar UVR exposure of individuals engaging in agricultural activities may lead to increased occurrence of associated negative health effects which will place heightened pressure on already burdened health care systems (Glanz *et al*., 2007). South African skin cancer prevalence rates vary by population group and are highest among people with light skin (Kellet *et al*., 2014). The 2016 National Cancer Registry report indicated that 31.9% of cancers diagnosed in White females and 35.4% of those diagnosed in White males were identified as basal cell carcinoma (BCC) while the same cancer constituted only 1.6% of all cancers diagnosed in Black females and 2.4% in Black males (NCR, 2020). Cortical cataracts are known to be partly cause by excess solar UVR exposure (Lucas *et al*., 2016). Studies have determined the prevalence of cataracts in South Africa in both rural and urban settings for example a prevalence of 44.0% was established in selected rural communities in the Limpopo Province while a prevalence of 27.0% was found in Cape Town (Cockburn *et al*., 2012; Khoza *et al*., 2020).

Therefore, the aim of this study was to evaluate the personal solar UVR exposure and to determine risk of excess solar UVR exposure of farmworkers on a macadamia nut and avocado farm in the Limpopo Province of South Africa. Additionally, we investigated the differences between the solar UVR measured on three different body sites during different seasons and compared the personal solar UVR exposure of mainly outdoor and indoor farmworkers to inform prevention and awareness campaigns for occupational sun exposure protection.

Methods

Study setting and participants

The study was conducted on a commercial macadamia and avocado farm in the Soutpansberg mountain range of the Limpopo province in South Africa (latitude: 22.58°S 29.7°E, altitude 1216 - 1392 m). Measurements were taken during three seasons, namely autumn (26 March 2018 to 18 May 2018), spring (05 November 2018 to 28 November 2018) and summer (04

February 2019 to 12 February 2019). Measurements were only taken in these three seasons and not in winter because it was anticipated the highest solar UVR would occur in these seasons and the lowest solar UVR in winter. Given the targeted approach of the study, all farmworkers on the farm were invited to participate in the study. Although the focus was on outdoor farmworkers, all farmworkers including those workers who mainly worked indoors were invited to participate in the study. Farmworkers who worked four hours or more of their shift outside, for at least 30 minutes at a time, were defined as outdoor farmworkers and workers who worked at least seven hours of their shift inside were defined as indoor farmworkers. Efforts were made to include outdoor farmworkers who performed a variety of different work activities including harvesting macadamia nuts and watering trees. Research ethics approval was granted by the North-West University Health Research Ethics Committee (NWU-00101-17-A1).

Polysulphone badge dosimetry

Polysulphone film (PSF) badges are small squares of film framed with cardboard borders. The optical absorbance of PSF changes when exposed to solar UVR in a manner that is proportional to the erythemal effective exposure dose (Peters *et al*., 2019). The specific change in absorbance of the PSF badges was determined using a spectrophotometer (DLAB SP-UV1000) at a wavelength of 330 nm. A calibration curve was created by calibrating the response of the PSF badges against the sun as source of UVR. A previously determined 5% correction factor (Geiss *et al*., 2003) was subtracted from the absorbance to counteract the effect of the dark reaction since due to logistical reasons, the PSF badges could not be analysed within 24 hours after exposure. A set of PSF badges were exposed to solar UVR and the change in absorbance for each was compared to solar UVR measured by a broadband radiometer located at the South African Weather Service in Pretoria, South Africa. The calibration curve that was created, was used to convert the change in absorbance in the PSF used to measure solar UVR exposure during data collection to J/m^2 (Peters *et al*., 2019). The solar UVR levels were then converted to SED, which is the standardized, biologically-weighted unit for the erythemal action spectrum with 100 J/m^2 equal to 1 SED (EN14255-3, 2018).

PSF badges were attached with the use of surgical tape on the shoulder, arm and top of the hat of participants for the duration of their shift. Daily ambient solar UVR were measured by placing two PSF badges in an unshaded area on a horizontal surface on the farm for the same time as badges were placed on the participants.

An occupational exposure limit (OEL) of 30 J/m^2 or 0.3 SED for 8 hours is prescribed by the ACGIH and the International Committee for Non-Ionizing Radiation (ICNIRP) using the ACGIH action spectrum (ICNIRP, 2010). The action spectrum refers to the relationship between the wavelength of the UVR and its photobiological effect (Geiss *et al*., 2003). Another recommended OEL has also been adopted using the international CIE action spectrum, where the OEL is 3.63 times that of OEL of 0.3 SED on the ACGIH action spectrum (EN14255-3, 2008). Although a CIE OEL of 1.09 SED for 8 hours is often used, alternatively a range of 1.0 - 1.3 SED is also given (ICNIRP, 2004; EN14255-3, 2008). As no such legal South African exposure limit for solar UVR is currently available, the solar UVR exposures in this study were interpreted and compared with the CIE action spectrum (upper limit of 1.3 SED) which provides a good approximation of the biological effect on the skin and eyes.

Data analysis

Descriptive statistics were used to describe the daily ambient solar UVR by season as well as the personal solar UVR exposures of the three body sites during different farm work activities on study participants. The one-way ANOVA test was used to establish differences between the mean ambient solar UVR levels of the three seasons. The solar UVR levels on the different body sites of both indoor and outdoor workers were not normally distributed and were therefore log-transformed prior to statistical analysis. The repeated measure ANOVA with a Greenhouse-Geisser correction and with the Bonferroni post-hoc correction was used to compare the means of the solar UVR found on the different body sites during one season for both outdoor and indoor worker groups. The independent t-test was used to compare the solar UVR measured on each body site between outdoor and indoor workers. The correlations between the solar UVR exposure of the different body sites within both outdoor and indoor workers were established using Pearson correlations. All statistical analyses were conducted using IBM SPSS statistical software (version 25) with statistical significance indicated by $p \leq 0.05$.

Results

Sample description

A total of 73 farmworkers consented to take part in the study of which 61 were outdoor farmworkers and 12 were indoor farmworkers. The numbers differed by season with 32 outdoor workers and three indoor workers included during autumn, and 19 outdoor workers and four indoor works were included during spring. During summer, 26 outdoor workers and five indoor workers were assessed.

Daily ambient solar UVR

The highest mean ambient solar UVR levels were measured during summer (35.0 ± 15.0 SED) which was higher, but not statistically different from that of spring (34.4 ± 19.49 SED) and autumn (18.9 ± 1.3) (F=2.0, p=0.2) (Figure 1). During the data collection periods, various weather conditions were noted including rain, clear skies, partly cloudy conditions, mist and fog in the region where the study site is located.

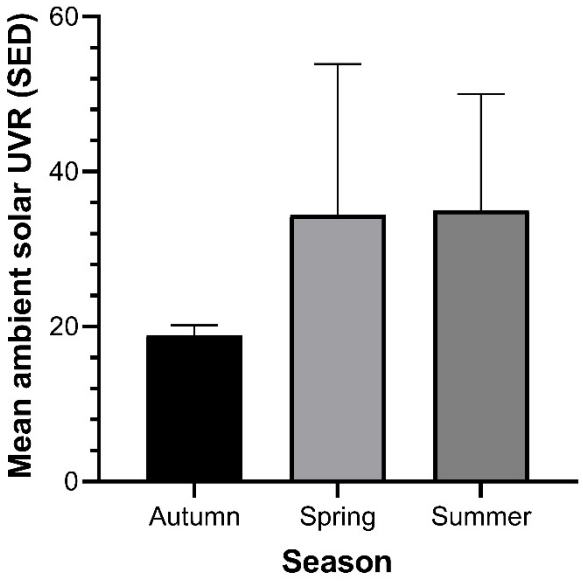

Figure 1: The mean ambient solar UVR levels (SED, 1 SED = 100 J/m^2) measured during the three seasons.

Personal solar UVR exposure by anatomical site and season

The mean daily personal solar UVR exposures during the three seasons and for the shoulder, arm and top of the head are given in Table 1.

Table 1: Personal solar UVR exposures of outdoor and indoor farmworkers by season and body sites as well as the percentage of personal solar UVR exposures by anatomical sites that exceeded the CIE OEL of 1.3 SED.

Body site			**Autumn**		**Spring**		**Summer**	
			Outdoor workers	**Indoor workers**	**Outdoor workers**	**Indoor workers**	**Outdoor workers**	**Indoor workers**
Shoulder	**n**		35	3	27	7	30	5
	Daily solar UVR exposure (SED)	**Mean**	7.5	3.1	8.6$^{\#a}$	0.2$^{\#}$	12.3^^{c}	1.9^
		95% CI	5.4 - 9.6	0.6 - 10.2	5.1 - 13.5	0.0 - 1.2	9.0 -16.4	0.7 - 4.8
	% > CIE OEL		97.5	50.0	89.3	28.6	100.0	80.0
Arm	**n**		35	3	27	7	32	5
	Daily solar UVR exposure (SED)	**Mean**	7.8*	3.2*	4.9$^{\#\#,a,b}$	0.3$^{\#\#}$	9.1^{,c,d}	1.9
		95% CI	6.1 - 9.8	1.5 - 11.2	2.7 - 8.7	0.0 - 1.2	6.9 - 11.6	0.7 - 6.2
	% > CIE OEL		97.7	100.0	81.5	14.4	100.0	60.0
Top of head	**n**		35	3	27	7	30	5
	Daily top of head solar UVR exposure (SED)	**Mean**	7.7**	2.2**	11.6$^{\#\#\#,b}$	0.2$^{\#\#\#}$	13.9^^^{,d}	2.6^^
		95% CI	4.5 - 11.6	0.6 - 5.9	7.2 - 17.4	0.0 - 1.4	10.4 - 17.9	0.8 - 6.6
	% > CIE OEL		92.3	50.0	92.6	42.9	96.7	80.0

Notes. n- Number of solar UVR samples, Mean=Geometric mean, 95% CI – Confidence interval, *,$^{\#,}$ ^ indicate statistically significant differences between solar UVR exposure of outdoor and indoor workers (independent t-tests), $^{a-d}$ indicates statistically significant differences between solar UVR exposure on body sites in a worker group (ANOVA with a Greenhouse-Geisser correction and with the Bonferroni post-hoc correction).

For outdoor workers during autumn, the highest mean solar UVR exposure was measured on the arm, while the lowest mean exposure was measured on the shoulder. Likewise, the arm also received the highest mean solar UVR exposure in the indoor worker group. The mean solar UVR exposure on the arm ($p=0.04$) and top of the head ($p=0.05$) differed significantly between outdoor and indoor workers.

During spring, the top of the head received the highest mean solar UVR exposure in the outdoor worker group while the arm received the lowest exposure (Table 1). When comparing the body sites, they differed statistically significantly from each other in the outdoor workers ($p\leq0.001$). Statistically significant differences were found between the solar UVR exposure on the shoulder and arm ($p\leq0.01$) and the arm and the top of the head ($p\leq0.001$) of the outdoor workers. The arm received the highest mean solar UVR exposure in indoor workers. The mean solar UVR exposure on all three body sites differed significantly between outdoor and indoor workers, namely shoulder ($p\leq0.001$), arm ($p\leq0.001$) and top of the head ($p\leq0.001$). Strong significant positive correlations were found in the outdoor workers between the solar UVR measured on the shoulder and both the arm ($p=0.88$, $p\leq0.001$) and top of the head ($p=0.84$, $p\leq0.001$), as well as between the arm and top of the head ($p=0.88$, $p\leq0.001$).

The top of the head received the highest mean solar UVR exposure in outdoor workers during summer while the arm received the lowest mean solar UVR exposure. The solar UVR on the body sites of the outdoor workers were statistically significantly different from each other with differences found between the arm and the shoulder ($p\leq0.01$) as well as between the arm and the top of the head ($p\leq0.01$). In the indoor worker group, the highest mean solar UVR exposure was measured on the top of the head.

The mean solar UVR exposure on the shoulder ($p\leq0.001$) and top of the head ($p=0.04$) also differed significantly between outdoor and indoor workers. Significant strong positive correlations were found between the solar UVR exposure measured on the shoulder of outdoor workers and both the arm ($p=0.69$, $p\leq0.001$) and top of the head ($p=0.62$, $p\leq0.01$), as well as between solar UVR on the arm and top of the head ($p=0.47$, $p\leq0.01$).

Personal solar UVR as a percentage of ambient solar UVR

The mean percentage of ambient solar UVR that was measured on the anatomical sites of the farmworkers during the three seasons is illustrated in Table 2. The body site of outdoor workers where the highest mean percentage of the ambient solar UVR was measured during all three seasons was the top of the head during spring while the lowest mean percentage on

the arm, also during spring. The highest percentage of ambient solar UVR on the body sites of indoor workers was measured during autumn on the arm, and the lowest measured on the top of the head during spring.

Table 2: Percentage of ambient solar UVR measured on the body sites of outdoor and indoor farmworkers

Body site		**Autumn**		**Spring**		**Summer**	
		Outdoor workers	**Indoor workers**	**Outdoor workers**	**Indoor workers**	**Outdoor workers**	**Indoor workers**
Shoulder	n	35	3	27	7	30	5
	Mean %	38.8	15.9	33.2$^{\#a}$	1.8$^{\#}$	37.0$^{\wedge c}$	6.4$^{\wedge}$
	95% CI	28.1 - 51.5	2.9 - 52.2	24.8 - 44.2	0.3 - 8.3	27.1 - 48.9	2.2 - 20.4
Arm	n	35	3	27	7	32	5
	Mean %	40.8*	16.2*	19.1^{,a,b}	3.8	27.4^{cd}	6.3
	95% CI	32.7 - 501.4	7.8 - 57.2	12.5 - 27.7	0.9 - 16.6	19.7 - 37.0	1.9 - 22.4
Top of head	n	35	4	27	7	30	5
	Mean %	35.4	11.2	45.1$^{\#\#,b}$	1.7$^{\#\#}$	41.5^{d}	8.4
	95% CI	16.2 - 57.4	3.1 - 30.6	35.0 - 57.2	1.9 - 10.3	31.0 - 53.5	2.6 - 29.7

Notes. n- Number of solar UVR samples, Mean = Geometric mean, 95% CI – Confidence interval, $^{*,\#,\wedge}$ indicate statistically significant differences between solar UVR exposure of outdoor and indoor workers (independent t-tests), $^{a\text{-}d}$ indicates statistically significant differences between solar UVR exposure on body sites in a worker group (ANOVA with a Greenhouse-Geisser correction and with the Bonferroni post hoc correction)

During both spring and summer, statistically significant differences in the mean percentage of ambient solar UVR were found between the shoulder and arm (spring: $p \leq 0.01$; summer: $p \leq 0.01$) and between the arm and the top of the head (spring: $p \leq 0.00$; summer: $p \leq 0.01$) of outdoor workers. When comparing the mean percentage of the solar UVR measured on the body sites between outdoor and indoor workers, a statistically significant difference was only found on the arm ($p=0.04$) during autumn. Statistically significant differences were found on all two body sites between outdoor and indoor workers during spring, namely the shoulder ($p \leq 0.001$) and top of head ($p \leq 0.001$). Significant differences were also found in summer when comparing the shoulder ($p=0.04$).

Personal solar UVR exposure by work activities

Both outdoor and indoor farmworkers carried out a variety of work activities during their workday for autumn (Figure 2), spring (Figure 3) and summer (Figure 4). The CIE OEL is included to illustrate exceedances of this limit by activity. The percentage of outdoor and indoor workers for whom personal solar UVR exposure on the different body sites exceeded the CIE OEL of 1.3 SED is provided in Table 1 (row labelled % > CIE OEL).

Although some work activities stayed the same across all three seasons (such as the activities of the macadamia nut factory, tending seedlings in the nursery and providing security at the gates) there were some work activities that depended on the season. For example, tree branches were broken down using a chipper only during autumn, harvesting macadamia nuts by picking them up from the ground only occurred during summer, while the sorting of avocados in the avocado warehouse occurred during autumn and summer. This variation in work activities was mostly found in the work of outdoor workers which also varied from day to day if they were general workers.

The type of work done by outdoor workers also included working in both mature and young orchards, carrying out activities such as picking up macadamia nuts from the ground during harvest, watering saplings and operating a tractor. An indoor worker working in the macadamia nut factory would, for example, carry out the same activities each day to process the nuts.

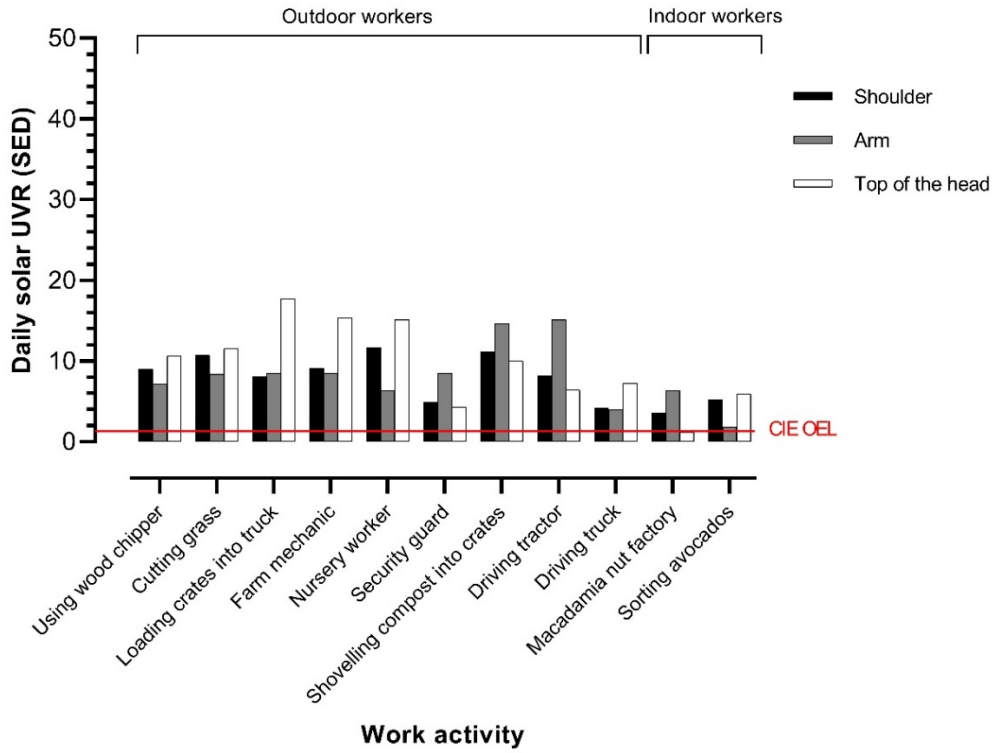

Figure 2: Mean solar UVR exposure on body sites according to work activity in autumn. The CIE OEL is shown by a red line.

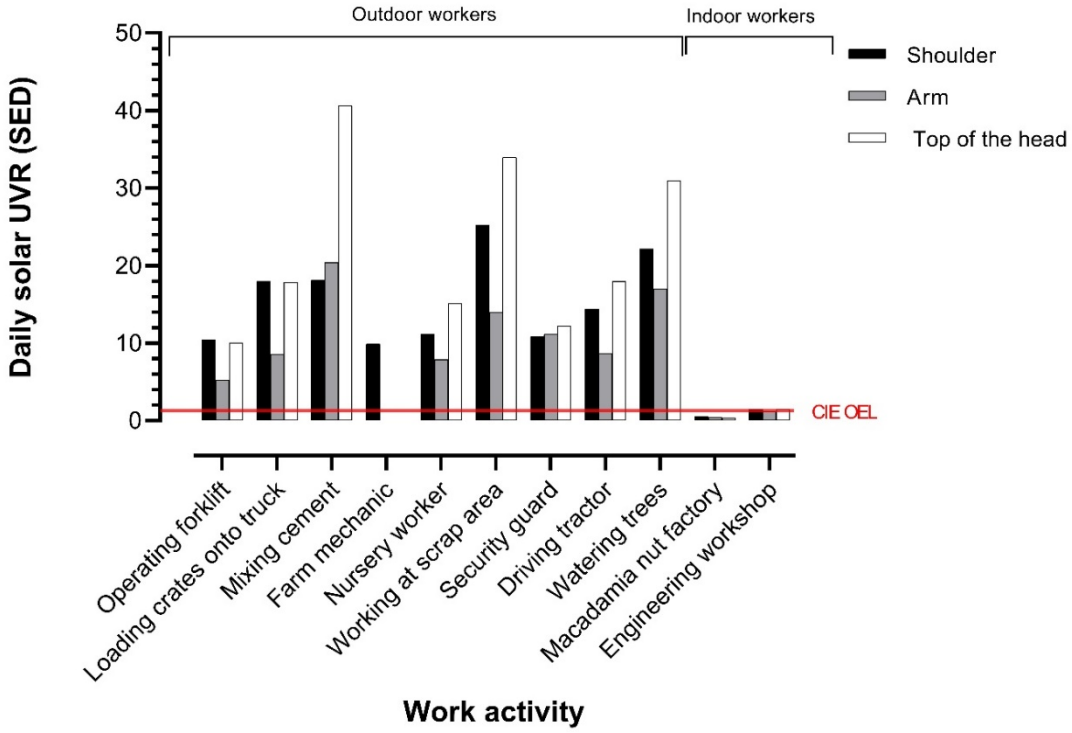

Figure 3: Mean solar UVR exposure on body sites according to work activity in spring. The CIE OEL is shown by a red line.

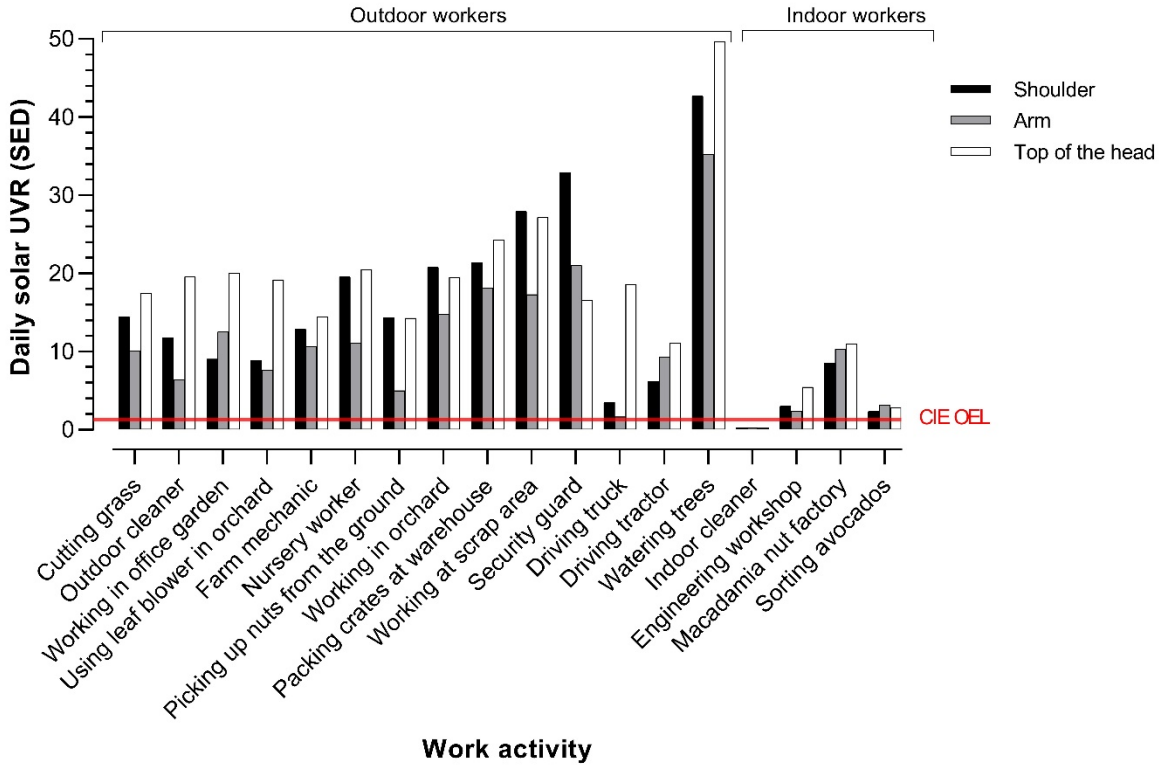

Figure 4: Mean solar UVR exposure on body sites according to work activity in summer. The CIE OEL is shown by a red line.

A few farmworkers switched between outdoor and indoor work activities. Their work activities would vary according to the work needs on the day such as cutting grass one day in the orchards and sorting avocados the next day in a warehouse. Hence, the differentiation between outdoor and indoor workers was not always clear-cut, and this is discussed in the limitations.

Discussion

This was the first known study to establish the personal solar UVR exposure of farmworkers in South Africa. There have only been two studies that evaluated occupational personal solar UVR exposure of outdoor parking area security staff (Nkogatse *et al*., 2019) and a school groundskeeper (Makgabutlane and Wright, 2015). This study goes beyond the earlier work by considering differences in body site and season.

In this study, the arm (in autumn) and the top of the head (in spring and summer) of outdoor workers received the highest mean solar UVR and percentage of solar UVR. These findings differ from studies that focused on cyclists and municipal outdoor workers who found that the top of the head or vertex were exposed to the highest level of solar UVR because it is horizontally orientated and, therefore, most directly facing the sun especially at azimuth (Kimlin

et al., 2006; Peters *et al*., 2019). Farmworkers engage in various postures depending on the work activity which may have resulted in another body site moving to a more horizontal orientation while the top of the head was positioned at an angle that would not receive as much solar UVR as when the worker was standing upright. The arm received some of the lowest exposure levels, possibly due to having been shaded by other anatomical structures such as the torso during work activities outdoors.

Among indoor workers, the arm received higher exposure levels likely due to passing an entrance that would allow solar UVR to enter the indoor work environment. Observations were made that indoor workers moved to outside areas during their break times or when fetching items from either the outside or other buildings before going back to their indoor workplace. Break times were also mostly spent in the shade provided by a canopied area. It was observed that once or twice per season, indoor workers were instructed to carry out outdoor work activities for less than two hours such as loading bags of macadamia nutshells or boxes of avocados onto customers' trucks. These outdoor activities resulted in the workers being exposed to higher levels of solar UVR than they normally would be had they only worked indoors.

Although there were no statistically significant differences between the body sites of outdoor workers during autumn, differences were found between certain body sites during spring and summer. These differences were found between arm and both the shoulder and top of the head but not between the latter two body sites. The reason that there were no significant differences found between the shoulder and top of the head may be that both sites are horizontally orientated and located relatively close to each other.

The lack of differences between the body sites of the indoor workers may be due to the short periods of time spent outside and exposed to solar UVR. The effect of this difference in the amount of time spent outside in the sun can also be seen in the significant differences found when comparing the solar UVR exposure of most of the body sites between outdoor and indoor workers.

Although direct comparison is difficult because of differences in the body sites used in different studies, the mean solar UVR exposure measured on the arm of outdoor farmworkers in this study during summer was more than five times the levels measured on the wrist of Polish, Austrian and Danish farmers, which ranged from 1.4 SED to 1.7 SED (Bodekær *et al*., 2015). Conversely, the mean solar UVR measured on the arm of the outdoor workers in our study

during spring was almost 10 SED lower than the median solar UVR that was measured on the arm of vineyard workers in Italy during the same season (Siani *et al*., 2011). However, the solar UVR measured on the arm of this study's outdoor workers in summer was almost twice the solar UVR measured on the same body site of the Italian vineyard workers during the same season A smaller but still noticeable difference was seen when the solar UVR on the arm during summer was compared to the solar UVR measured on the wrist of New Zealand horticultural workers where the solar UVR was almost 50% less than in the current study (Hammond *et al*., 2009). The higher exposure of the South African farmworkers when compared to most of these farmers and horticultural workers may be due to the higher ambient solar UVR levels in South Africa related to latitude and altitude. The Soutpansberg mountain range, where the farm is located, is just north of the Tropic of Capricorn (latitude 23.5 °S) which is closer to the equator than the mentioned European countries or New Zealand (Hammond *et al*., 2009) leading to higher ambient solar UVR levels. In 2004, the average daily ambient solar UVR levels in South African was determined by the World Health Organization (WHO) to be 41.11 SED, while the ambient solar UVR level for Austria and New Zealand during the same year was 18.88 SED and 24.87 SED, respectively (WHO, 2019).

The personal mean solar UVR exposure on the arms of outdoor farmworkers in our study during summer was more than 15 times that which was measured on the arms of South African outdoor parking area security staff which was only 0.29 SED (Nkogatse *et al*., 2019). The reason for the large difference may be the difference in activities carried out by the two jobs such as the relatively stationary position of the parking area security staff when compared to the farmworkers who generally move frequently while working. Differences in work activities leads to differences in the solar UVR exposure levels (Salas *et al*., 2005). Given that the farmworkers worked in a rural area while the parking area was an urban area, may also have been a contributing factor to this difference in solar UVR exposure in terms of albedo (a factor influencing levels of surface solar UVR). The amount of solar UVR that was reflected may have differed between the rural and urban area. There may also have been more shading structures in the parking area that shielded the parking area security staff from direct solar UVR exposure than in the open areas of the farm.

The differences found between the solar UVR exposure of outdoor and indoor farmworkers during autumn are comparable a group of Danish outdoor workers who were exposed to approximately four times higher solar UVR than Danish indoor workers (Grandahl *et al*., 2018). The higher differences in spring and summer may be linked to the higher ambient solar UVR outside which increased the solar UVR exposure of the outdoor workers but the indoor

environments and solar UVR exposure of indoor workers stayed relatively the same across seasons.

Although the percentage of solar UVR exposures that exceeded the CIE OEL of 1.3 SED varied between the body sites as well as over the three seasons, more than 80% of outdoor workers received solar UVR exposure that exceeded the CIE OEL on all body sites during all three seasons. The percentage of solar UVR exposures that exceeded the CIE OEL varied noticeably among the indoor workers between the different body sites and across seasons which may be in part due to the small sample sizes in the indoor worker group. Similar percentage were found on the back and arms of Italian vineyard workers (Siani *et al*., 2011) and Italian ski instructors (Siani *et al*., 2008). However, other studies found much lower percentages, e.g. 41% on the hardhats of Canadian construction workers (16). While the CIE OEL of 1.3 SED was designed as the guideline to determine the maximum radiation that is biologically effective for the human skin and eye, the standard was created using the minimum erythemal dose (MED) for fair skin (ICNIRP, 2010). It has been criticized as being too strict for populations with more deeply-pigmented skin as it does not factor in the individual's baseline genetic photoprotection (Milon *et al*., 2007). A study that evaluated the skin colour of the same farmworker group who took part in this study found that the skin colour of 48% of the Black African farmworkers could be objectively classified as Type VI (Linde *et al*., 2020). The exposure to solar UVR at levels that exceed the CIE OEL may not ultimately result in skin cancer in most of the farmworkers who participated in this study due to their genetic photoprotection. However, increased pigmentation of the skin does not protect against the effects of excessive solar UVR exposure on the eyes (Agbai *et al*., 2014), and immunosuppression (Fajuyigbe and Young, 2016) which may still indicate a health risk linked to the exposure of this population to solar UVR that exceeds the CIE OEL.

The percentages of ambient solar UVR that farmworkers on the macadamia and avocado farm were exposed to on the three body sites over the three seasons were higher than most solar UVR exposures reported in other studies. For example, the percentages of ambient solar UVR that farmers' exposure on the wrist in Denmark, Poland, Austria, and Spain were less than 10% in each case while the faces of Austrian farmers were exposed to 12% (Schmalwieser *et al*., 2010; Bodekær *et al*., 2015). The percentage of ambient solar UVR measured on the wrists of New Zealand horticultures during summer, which was 24%, was also lower than the percentage of solar UVR measured on the arm during summer in our study (Hammond *et al*., 2009). The only instances where the percentages were higher than those found in our study, were the 72% and 100% measured on the back of Italian vineyard workers during summer

and autumn, respectively, as well as 67% of the ambient measured on the arm in autumn (Siani *et al*., 2011). A school groundskeeper in Pretoria, South Africa was exposed to a comparable percentage of the ambient namely 84% (Makgabutlane and Wright, 2015) which may indicate that activities related to agriculture / horticulture and geographical location has an influence on solar UVR exposure.

The pattern of solar UVR exposure on the different body sites of outworkers varied when engaging in different work activities. The characteristics of the area where the work activity was performed also influenced the level of solar UVR received by the different body sites. This is illustrated by the difference in solar UVR exposure of outdoor farmworkers working in the established orchards and those watering saplings in the young orchards. The solar UVR measured on the body sites of the workers in the young orchards were at least 10 SED higher than the level measured on all the body sites of workers working in the established orchards where the trees were larger and had more foliage. This effect of foliage on solar UVR exposure was also found by Siani *et al*. (2011) in Italian vineyards where higher solar UVR exposures during spring than summer which were attributed by the authors to a seasonal decrease in foliage in the vineyard during spring which resulted in higher levels of solar UVR reaching the workers.

We evaluated the solar UVR exposure of different body sites on farmworkers in Africa to determine which site received the highest solar UVR exposure during different seasons. Although efforts were made to analyse one PSF badge from each body site for each participant, some PSF badges were lost during the data collection while the analyses of some badges could not take place due to contamination. Six badges could not be used due to dust on the film interfering with the accurate measurement of UVR absorbance. This study was carried out on one large macadamia nut and avocado farm in one province and hence findings may not be readily extrapolated to determine the solar UVR exposure of farmworkers in other provinces or on other type of farms due to the effects on personal solar UVR exposure, e.g. geographical location influencing altitude and latitude and behavioural differences in work activities. Further research regarding the personal solar UVR of different types of farmworkers in different regions of the country and continent is needed. The small number of indoor workers made some comparisons uncertain. The higher than normal solar UVR exposure experienced by one or two indoor workers may have had a bigger effect than would have been found if the sample size had been larger. A larger number of indoor farmworkers should be included in further studies to identify a more detailed pattern of their solar UVR exposure. The PSF badges were unable to provide the hourly solar UVR exposure of a farm worker which would

provide the changing diurnal pattern of exposure when solar UVR exposures occur. Electronic dosimetry would provide this information.

Conclusions

The exposure of the majority outdoor farmworkers to solar UVR on the shoulder, arm and top of the head exceeded the recommended CIE OEL during all three seasons that were evaluated, namely autumn, spring and summer. The assumption that personal photoprotection interventions should only be applied during summer in geographic areas of South Africa, such as the Limpopo Province, needs to be revised in a comprehensive photoprotection plan for occupational exposure especially for farmworkers. As is the case with several other outdoor occupations, farmworkers are unable to move their work activities to areas with more shade thus preventing workers' ability to decrease their solar UVR exposure. Appropriate alternative photoprotective measures such as protective clothing should be implemented by employers to protect the health of these outdoor workers.

Acknowledgments. We thank the farm owners and farmworkers for participating in the study. We would also like to thank Ms Cynthia Ramotsehoa for her help in the analysis of the polysulphone badges.

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CHAPTER 7: CONCLUSIONS, LIMITATIONS AND FUTURE STUDIES

This chapter provides a summary of the conclusions and limitations of this thesis, and also proposes recommendations for both control measures of excess sun exposure and future studies in this field. Special attention is directed to the aims, objectives and hypothesis of this thesis, as presented in Chapter 1. Recommendations directed to both farmers, as employers, and farmworkers, as employees, are proposed on how to improve sun safety on a farm when working in the sun. In addition, recommendations are made to health care professionals regarding the subjective and objective measurement of skin colour which can play an important part in determining the risk posed by solar ultraviolet radiation (UVR) exposure during work to an occupational group working on a farm.

7.1. Conclusions

7.1.1. Skin colour and characterization

The characterization of an individual's skin colour provides an indication of the magnitude of genetic photoprotection provided by the individual's skin (Fitzpatrick,1988). Although a limited number of studies have characterised the skin colour of South Africans in an urban occupational setting (Karsten *et al*., 2013; Wright *et al*., 2015), similar studies have not been done in a South African rural setting, specifically an area with a relatively high latitude and altitude.

The first objective of this thesis was to compare, using skin bioengineering measurements the differences in skin colour (individual typology angle (ITA°)) and melanin content of farmworkers on a macadamia nut and avocado farm in the Limpopo Province of South Africa. Chapter 3 of this thesis presents the subjective and objective skin colour of this farmworker group and has recently been published in the journal *Skin Research and Technology* (Linde *et al*., 2020). Subjective constitutive skin colour was determined using a Fitzpatrick Skin Phototype (FST) questionnaire while objective skin colour of both facultative and constitutive skin was determined using bioengineering methods that involved spectrophotometry.

Objective measurements characterised the skin colour of Black African farmworkers as either FST V/Brown (52%) or FST VI/Dark (48%) while skin colour of White farmworkers fell in either FST I (10%), FST II (70%) or FST III (20%) categories. However, previous studies characterised the skin colour of individuals born in South Africa to be in a range from FST I to

FST V (Karsten *et al*., 2013). This fact only partially concurs with the findings of this study due to the almost 50% of the tested Black African farmworkers falling in the FST VI category. This disparity may illustrate a genetic difference found among individuals living in the Limpopo Province compared to other geographical areas of South Africa. Additionally, the majority of these Black African farmworkers regarded their skin as being lighter than what was objectively measured. The social norm that a lighter skin colour is more attractive has been documented previously among Black African individuals in South Africa as well as in other African countries (Dlova *et al*., 2014).

The back of the hand was chosen to represent facultative skin (sun exposed) while the inner upper arm was chosen to represent constitutive (sun protected) skin colour. Statistically significant differences were found between the facultative and constitutive skin when using both objective measurement methods, namely ITA° and melanin index (MI). These significant differences were found among both the Black African (ITA°, p=0.00; MI, p=0.00) and White farmworkers (ITA°, p=0.02; MI, p=0.01). More statistically significant differences were found between other body sites in both worker populations which may be due to the different work positions that were adopted which led to different levels of solar UVR exposure occurring on each site.

Knowledge regarding the skin colour and, therefore, the genetic photoprotection profile of an occupational group is a useful tool in designing a programme to protect the group against the health effects associated with excess exposure to solar UVR. An individual with a darker skin colour can be exposed to higher levels of solar UVR before health effects such as erythema (sun burn) occurs (Wright *et al*., 2013) and thus requires a different array of photoprotective measures than an individual with a lighter skin colour. A photoprotection program that workers regard as relevant to them due to evaluation of their skin colour, may be an important factor for an effective program.

The first objective of this thesis was achieved and the differences in the facultative and constitutive skin colour and melanin content were measured and compared.

It was hypothesised (Hypothesis 1 in Chapter 1) that there is a significant difference in the objectively measured ITA° and MI between facultative and constitutive skin of farmworkers on a macadamia nut and avocado farm in the Limpopo Province of South Africa. In Chapter 3, it is reported that a statistically significant difference was found between the facultative (back of the hand) and the constitutive (inner upper arm) skin of both Black African (ITA°, p=0.00; MI,

p=0.00) and White farmworkers (ITA°, p=0.02; MI, p=0.01). This is similar to what was found in urban South African workers (Wright et al., 2015). Therefore, the hypothesis is accepted.

7.1.2. Ocular photoprotective measures used by farmers

Photoprotective measures or sun safety measures are designed to decrease individuals' exposure to solar UVR. A variety of these measures are available with the wearing of sunglasses or hats specifically used to protect the eyes against solar UVR exposure (Lim *et al*., 2017). To our knowledge the use of photoprotective measures by workers has not been previously evaluated in a South African agricultural setting.

The second objective of this thesis was to assess the solar UVR practices, in particular the use of ocular protective measures, of South African commercial farmworkers on a macadamia nut and avocado farm. These practices towards ocular photoprotective measures are reported in Chapter 4 of this thesis in a manuscript that was submitted for publication to the journal *Photochemistry and Photobiology*.

It was found that 80% of outdoor farmworkers reported never wearing sunglasses while working including all the female workers. Sunglasses provide effective protection to the eyes if their design includes UVR limiting lenses and a tight fit to the face (Backes *et al*, 2019). While 61% of outdoor farmworkers reported always wearing a hat, the type of hat that was worn did not necessarily provide sufficient ocular protection against solar UVR exposure. Workers, especially male workers, preferred wearing caps and visors (40%) with only 30% reporting wearing broad-brimmed hats. Broad-brimmed hats provide the best protection to the whole face when compared to caps and visors (Backes *et al*., 2018).

Although the majority of the participants in our study have a dark skin colour (Chapter 3), the ocular health of the participants can still be compromised if they are exposed to high levels of solar UVR. It was established from the findings of Chapter 6 that the outdoor farmworkers on the macadamia nut and avocado farm are exposed to solar UVR levels that exceed the CIE OEL of 1.3 SED. The exposure limit was established in order to protect individuals' skin and eyes which indicates that although the participants' skin has a degree of genetic photoprotection, their eyes were at risk of UVR-related damage due to their negligent use of ocular photoprotective measures.

Farmworkers' socioeconomic status as well as fashion trends may influence their use of ocular photoprotective measures. The cost of sunglasses that provide sufficient UVR protection may

prevent outdoor farmworkers from wearing them as they are not part of the uniform provided by their employer. Male fashion trends tend to include the wearing of caps and not broad-brimmed hats (Reeder *et al*., 2011) which may contribute to male outdoor farmworkers' choice of hats.

This objective was achieved and the self-reported use of ocular photoprotective measures by outdoor and indoor farmworkers while working in the sun was established with the aid of questionnaires (Appendix D).

It was hypothesised in Chapter 1 that the ocular protection practices, such as wearing hats and sunglasses, among a group of South African commercial farmworkers on a macadamia nut and avocado farm in the Limpopo Province while working in the sun, is irregular (corresponding to similar published studies). These findings show that the use of photoprotective measures to protect the eyes is inadequate (80% not wearing sunglasses) and that the hypothesis can, therefore, be accepted.

7.1.3. Photoprotection provided by clothing

Clothing is used as a measure to prevent high levels of solar UVR from reaching the skin (Lim *et al*., 2017). The amount of solar UVR that is either absorbed, transmitted or reflected by clothing (Stankovic *et al*., 2009) is determined by factors such as the thickness of the material and the tightness of its weave (Ghazi *et al*., 2014). The third objective of this thesis was to determine the degree/level of photoprotection provided by the clothing worn by farmworkers using polysulphone badges on the shoulder underneath and on top of the clothing worn by farmworkers on the macadamia nut and avocado farm. The level of photoprotection is reported in Chapter 5 in a manuscript which has been submitted for publication to the journal, *Annals of Work Exposure and Health.*

The solar UVR underneath clothing differed significantly from solar UVR measured on the outside of clothing during autumn ($p \leq 0.00$), spring ($p \leq 0.00$) and summer ($p \leq 0.00$). This can be due to solar UVR being prevented by the tightness of the weave of the fabric from travelling through the clothing to the skin underneath. Classifying clothing worn by farmworkers according to the level of solar UVR that was allowed to transmit through the clothing, showed that only 6% of clothing did not meet the minimum required protection against UVR using the criteria found in AS/NZS 4399:2017 (The Australia/New Zealand standard was applied since no South Africa standard exists). Over 80% of clothing was classified as providing excellent protection.

Farmworkers are provided with a uniform by their employer consisting of long sleeved overalls and a short sleeved t-shirt underneath. It was reported that 79% of workers removed the long sleeve jacket of the overall in warm weather which may have compromised the photoprotection provided by the uniform. The objective was accomplished since the photoprotection provided by farmworkers' clothing was quantified.

7.1.4. Solar ultraviolet radiation exposure

Farmworkers are at high risk of exposure to solar UVR due to the work they perform outdoors (ICNIRP, 2010). Although it has been established that high levels of ambient solar UVR are found in South Africa (WHO,2019), a limited number of studies have evaluated the solar UVR exposure of South African outdoor workers such as outdoor parking area security staff (Nkogatse *et al*., 2019) and a factotum on school grounds (Makgabutlane and Wright, 2015) but none focused on farmworkers.

The fourth objective of this study was to assess the personal solar UVR exposure of outdoor farmworkers on a macadamia nut and avocado farm in the Limpopo Province of South Africa during autumn, spring and summer while performing their various work activities. This was done by placing polysulphone badges on their arms, on top of the shoulder and on top of any head covering worn. Chapter 6 of this thesis reports the personal solar UVR of these outdoor farmworkers on different anatomical positions during the three seasons and this manuscript has been submitted for publication to the journal *Annals of Work Exposure and Health*. While the majority of participants carried out work activities such as cutting grass, picking up nuts and watering trees, a small number of indoor farmworkers, working in the macadamia nut factory, sorting avocados in the warehouse, performing engineering work or cleaning indoors and they were also included to establish if the solar UVR exposure of the outdoor farmworkers differed from those of indoor farmworkers on the same farm.

The results in Chapter 6 show that more than 80% of outdoor farmworkers received solar UVR exposure that exceeded 1.3 SED on all three of the anatomical positions evaluated and, consequently, also exceeded the CIE exposure limit. The percentage of outdoor farmworkers with solar UVR exposure that exceeded the exposure limit was more than 90% across the three anatomical positions during autumn. While a slightly lower percentage received excess exposure on the shoulder and arm during spring - 89% and 82% respectively- the solar UVR measured on the top of the head during the same season also exceeded 90%. Furthermore, the solar UVR exposure on both the shoulder and arm of all outdoor farmworkers exceeded

the exposure limit during summer, with the solar UVR on the top of the head of only 3.3% of outdoor farmworkers, measuring 1.3 SED or below.

The mean solar UVR exposure of 9.1 SED measured on the arm of the outdoor farmworkers in our study was higher than those of farmers and farmworkers from European countries such as Austria (1.4 SED), Poland (1.7 SED), Denmark (1.5 SED) and Spain (2.6 SED) (Bodekær *et al*., 2015), as well as horticultural workers in New Zealand (5.6 SED) (Hammond et al., 2009) during summer. Although the solar UVR exposure of 10.3 SED on the arm of Italian vineyard workers during spring was higher than what was measured on the arm of the outdoor farmworkers (4.9 SED) that participated in our study during the same season, the solar UVR exposure of 5.9 SED on the same anatomical position of the Italian vineyard workers during summer was lower than what was measured in our study (Siani *et al*., 2011).

It should, however, be noted that the skin colour of the majority of the farmworkers in our study was categorized as either FST V or FST VI, which indicates a higher genetic photoprotection (Chapter 4). The occupational exposure limits for UVR exposure were formulated to protect workers with light skin or “worst case scenario” (ICNIRP, 2020), which means that it is possible that a large number of the participants in this study will not be at a high risk of developing solar UVR related health problems although their solar UVR exposure exceeded the exposure limit. However, farmworkers with deeply-pigmented skin may still be at high risk of developing ocular diseases such as cataracts (Lucas *et al*., 2016). A study by Khoza *et al*. (2020) found a cataract prevalence of 44% in the selected areas of the same province that our study was conducted in, namely the Limpopo Province, which may indicate that ocular exposure to solar UVR should be a notable concern when implementing photoprotective measures in this geographic area. The inadequate use of ocular photoprotection currently found amongst outdoor farmworkers in this study, as communicated in Chapter 4, also argues for an increased focus on this type of photoprotection measure in the area.

Statistically significant differences were found between the solar UVR received by outdoor farmworkers and indoor farmworkers on the arm ($p=0.04$) and top of the head ($p=0.05$) during autumn, all three anatomical positions ($p\leq 0.001$) during spring as well as the shoulder ($p\leq 0.001$) and top of the head ($p=0.04$) during summer. These differences indicate that the longer period of time that outdoor workers spend outside working, has a significant impact on their solar UVR exposure and, therefore, their risk of being exposed to solar UVR at levels that may pose a risk to their health.

The different body postures required to carry out various work activities have been linked to the varying levels of solar UVR found on different body positions of outdoor workers (Siani *et al*., 2011). This variation is also noted in our study. Statistically significant differences were found between the arm and both the shoulder and top of the head during spring and summer, but not autumn. The top of the head and shoulder were both horizontally positioned which may have led to a more similar exposure to solar UVR than the arm, which is located on the vertical plane. In addition, the top of the head received the highest mean solar UVR exposure during two of the three seasons, namely spring and summer, which is consistent with findings from other studies attributing to the finding of the horizontal plane of the top of the head when standing upright (Kimlin *et al*., 2006, Peters *et al*., 2019). However, not all working postures require the worker to stand upright, which may be the reason that the arm received the highest mean solar UVR during autumn. The effect of different postures on solar UVR exposure may be a factor that needs to considered when deciding on effective photoprotective measures for specific outdoor workers.

The fourth objective of this study was achieved and the assessment of the personal solar UVR exposure of outdoor farmworkers during autumn, spring and summer while carrying out their different work activities of a group of farmworkers on a macadamia nut and avocado farm in the Limpopo Province of South Africa by using polysulphone badges placed on their arms, top of the shoulder and top of any head covering, was completed.

In Chapter 1, it was hypothesised that the personal solar UVR of a group of South African outdoor farmworkers on the macadamia and avocado farm exceeds the highest level of the CIE exposure limit range of 1.3 SED per eight hours during autumn, spring and summer. These findings indicate that the hypothesis can partially be accepted because although the solar UVR exposure on all anatomical positions of outdoor farmworkers during all three seasons did not exceed the exposure limit, the majority did indicating that solar UVR poses a potential health risk to farmworkers in this geographic area not only during summer but also during spring and autumn. All anatomical positions of the outdoor workers did not receive solar UVR exposures that exceeded the OEL due to the fact that these workers were working in outside areas that had sufficient shade such as under a tree or that they adopted work postures that shielded an anatomical position from solar UVR.

7.1.5. Summary

The solar UVR exposure of outdoor workers such as farmworkers needs to be carefully managed to ensure that they experience the beneficial health effects and not the health effects

that are harmful. This fine balance cannot be achieved if the knowledge of the workers' genetic protection provided by skin colour, their current use of ocular photoprotective measures and their exposure to solar UVR while working are lacking. The findings of this study regarding a group of farmworkers on a macadamia nut and avocado farm in the Limpopo Province of South Africa, confirm that the constitutive skin colour (ITA°) and melanin index of the constitutive skin of the farmworkers were statistically different than what was measured on their facultative skin. The skin colour of the majority of the workers could also be classified as either FST V or FST VI, which indicates a high level of photoprotection of the skin. This genetic photoprotection does not extend to the eyes which means that the inadequate use of ocular photoprotective measures by the outdoor farmworkers in this study, poses a risk of developing ocular diseases such as cataracts. The solar UVR exposure of the majority of outdoor farmworkers exceeded the CIE OEL of 1.3 SED on all three anatomical positions that were evaluated during autumn, spring and summer. The mean solar UVR exposure of the outdoor farmworkers in our study was higher than the exposure of farmers and farmworkers that were reported in studies conducted in other countries with one exception in spring (Hammond *et al*., 2009; Bodekær *et al*., 2015; Siani *et al*., 2011). The majority of clothing worn by the farmworkers in our study provided excellent protection as long as the clothing was worn against solar UVR being transmitted through the fabric to the skin underneath.

In conclusion, the general aim of this thesis, to quantify the differences in skin colour and melanin content of facultative and constitutive skin of farmworkers on a macadamia nut and avocado farm in the Limpopo Province of South Africa, as well as assessing the solar UVR practices, in particular the use of ocular protective measures, of those farmworkers together with their occupational exposure to solar UVR to determine if the exposure poses a risk to their health has, therefore, been achieved.

7.2. Recommendations

Recommendations based on the findings reported in Chapter 3-6 are communicated in the section below. The aim of all recommendations is to ensure that outdoor farmworkers on the farm are exposed to solar UVR levels that are not harmful to their health. Recommendations have been ordered according to the hierarchy of control used in the field of occupational hygiene. The hierarchy of control signifies the ranking of different types of control measures managing exposure to environmental stressors from the most effective to the least effective (Maguire and Spurr, 2017).

Recommendation 1: As reported in Chapter 6, outdoor farmworkers were exposed to solar UVR that exceeded the CIE OEL and, consequently, posed a risk to the health of the workers. Outdoor workers such as farmworkers are not in a position to choose to work in the shade but should be given the option to take their breaks in the shade. It was observed that canopied structures where outdoor farmworkers could take breaks were available at the older established orchard. However, at the new orchards where the trees were not big enough to provide any shade, no additional shading was provided. It is recommended that a sufficient number of canopied structures constructed of solid material such as corrugated iron, should be built alongside the new orchards, providing ample space to accommodate and all outdoor farmworkers working in these specific orchards.

Recommendation 2: Two action UVR exposure limits have been created, the one using the ACGIH action spectrum (0.3 SED per eight hours) and the other using the International Commission on Illumination (CIE) action spectrum (1.0 to 1.3 SED per eight hours) (ICNRIP, 2010; Siani *et al*., 2011; ACGIH, 2020). However, an OEL for exposure to solar UVR is currently not included in any regulation of the Occupational Health and Safety Act (OHS Act 85 of 1993). This Act and its regulations apply to all non-mining industries in South Africa such as the agricultural sector. Irrespective of the absence of an OEL for solar UVR exposure, Section 8 of the Act states that ”every employer shall provide and maintain, as far as reasonably practicable, a working environment that is safe and without risk to the health and safety of his employees” (OHS Act 85 of 1993). Therefore, it is recommended that the occupational exposure limit for solar UVR should be included in South African occupational health legislation to provide guidance to employers on the solar UVR levels that their workers can safely be exposed to and, in doing so assist the employers in providing a safe work environment to their workers as required by law.

Recommendation 3: A photoprotection program, also referred to as a sun safety programme, should be a comprehensive program that aims to protect outdoor workers who are exposed to the sun (Buller *et a*l., 2019). Such a

program needs to change the behaviour of workers (Cioffi *et al*., 2002). Due to the inadequate use of ocular photoprotective measures by the outdoor farmworkers reported in Chapter 5 and their exposure to high levels of solar UVR while working, it is recommended that a comprehensive ocular photoprotective program should be created for this specific workplace to be able to manage the exposure of outdoor farmworkers' eyes to solar UVR. This program should include administrative policies regarding the implementation of various ocular photoprotective measures that will be discussed in detail in other recommendations proposed in this chapter (Recommendation 9).

Recommendation 4: Chapter 3 refers to the findings that the skin colour profile of the farmworkers on the specific farm differ from the profile reported in a study conducted in an urban area situated in a different geographic area of South Africa (Kasten *et al*., 2013). This difference shows that the skin colour profile and, therefore, the genetic protection against UV-related health problems may differ between workplaces in various geographic areas. The skin colour profile of workers in one workplace can consequently not be extrapolated to that of workers in another workplace to determine the photoprotective needs of the second workplace. It is recommended that the skin colour of farmworkers should be characterised regularly as part of a health risk assessment to determine the photoprotective needs of the current farmworker group.

Recommendation 5: It is recommended that a solar UVR risk assessment should be conducted if any changes in work activities or photoprotective control measures occur. This risk assessment should include the measurement of the personal solar UVR exposure of outdoor farmworkers to determine if the changes influenced their exposure.

Recommendation 6: Blindness caused by cataracts is not only prevalent in South Africa but specifically also in the Limpopo Province where the study was conducted (Khoza *et al*, 2020). The early detection of cataracts has been identified as an important preventative measure to safeguard against avoidable blindness (Pratap and Kokil, 2019). Similarly, screening and self-examination of skin to detect skin cancer at an early

stage is considered a preventative measure, especially in individuals with light skin (Zink *et al*., 2017). The lack of screening is also a key factor in skin cancer being diagnosed at a later stage in Black Africans than Whites when the tumours are more aggressive although the incidence is much less frequent in Black Africans (Lucas *et al*., 2016). It is, therefore, recommended that annual medical screening of workers' skin and eyes by an occupational medical practitioner should be arranged for the farmworkers so that early signs of developing skin cancer and ocular diseases such as cataracts can be detected.

Recommendation 7: Madgwick *et al*. (2011) found that British construction workers showed higher use of photoprotective measures if they had previously received some type of sun safety awareness training. The positive impact of successful photoprotective or sun safety awareness campaigns is not only evident in the increased protection performed by the workers themselves but also in the knock-on effect where the workers' families are also informed about the ways to protect themselves while in the sun (Glanz *et al*., 2009). It is recommended that an awareness campaign regarding the health effects related to excess solar UVR exposure, the importance of using photoprotective measures including those that protect the eyes such as broad-brimmed hats and sunglasses, is implemented on the farm.

Recommendation 8: The scheduling of work to a time of day when the ambient solar UVR levels are not at the highest levels, is seen as one of the most effective measures to reduce workers' exposure to solar UVR (Greinert *et al*., 2015). However, it is acknowledged that this is not often possible in workplaces such as farms. It would, for example, not be practical to schedule the harvesting of macadamia nuts or avocados only for certain parts of the day as the crops need to be harvested as soon as possible to prevent diminished crop yield and quality. Another example is the watering of new orchards of saplings which need to happen on a strict schedule for the saplings to survive. It is recommended that in those instances where it is practical, work that needs to take place in open areas without shade, should be scheduled for early in the mornings and not in the middle of the day.

Recommendation 9: The inadequate use of ocular photoprotective measures such as wearing sunglasses and broad-brimmed hats among the outdoor farmworkers who participated in this study (Chapter 5) indicated that a risk is posed to the eye health of workers. Peters *et al*. (2016) found that workers who received photoprotective measures as part of a uniform that was compulsory to be worn, were more likely to apply these methods. Currently, the type of hat most commonly provided as part of the uniform is a beanie. It is, therefore, recommended that broad-brimmed hats should be provided instead of beanies and that these hats are seen as part of the uniform that farmworkers are required to wear. The benefit of wearing a broad-brimmed hat versus other types of hats should be emphasised in the awareness campaign.

Recommendation 10: It was observed that outdoor farmworkers remove their long sleeve overall jackets in hot weather exposing their arms to solar UVR exposure (Chapter 6). In order to protect their arms, it is recommended that protective arm covers, that are certified UVR protective, should be supplied to the workers. These protective arm covers should be made of material that provide a cooling effect by wicking away moisture. The CANSA seal of approval is designed to certify UVR protective clothing in South Africa (CANSA, 2019). Care should be taken that all arm covers that are provided, carry this certification.

Recommendation 11: The application of sunscreen is one of the primary photoprotective measures recommended by organizations such as the American Academy of Dermatology (Cestari and Buster, 2017). It is especially recommended that individuals with light skin apply sunscreen regularly (Lucas *et al*., 2016). The solar UVR levels that farmworkers were exposed to were high as reported in Chapter 6. It is recommended that a water resistant, broad spectrum sunscreen with a SPF of 20 or higher should be made available to farmworkers. Individuals should apply 2 mg of sunscreen per centimetre of skin every two hours.

7.3. Limitations

The following limitations were identified that are related to the quantification of the differences in skin colour and melanin content of facultative and constitutive skin as well as the assessment of the solar UVR practices, in particular the use of ocular protective measures of farmworkers together with their occupational exposure to solar UVR.

Limitation 1: The majority of the participants in this study identified themselves as Black African while the remaining small percentage identified themselves as White. This is in line with the population group distribution provided for the whole Limpopo Province in the 2011 Census (STATSSA, 2014). The small population of White farmworkers and the total absence of Coloured or Indian/Asian farmworkers due to the population demographics of the specific worker population on the farm, limit the representability of the findings that can be made regarding the White farmworkers and result in the inability to make any finding regarding the other two population groups in South Africa.

Limitation 2: The personal solar UVR exposure of a group of indoor farmworkers was also included in the study to act as a control group for the personal solar UVR exposure of outdoor farmworkers. By including the indoor workers in the study, insight was gained into the exposure of this group of workers. However, the higher than anticipated solar UVR exposure experienced by one or two indoor workers, may have had a more pronounced effect if the sample size for indoor workers had been larger.

Limitation 3: This study is the first that quantifies the personal solar UVR exposure of farmworkers in South Africa. However, it will not be possible to extrapolate this study's findings to other farmworker populations in South Africa other than who work on macadamia nut and avocado farms in the Limpopo Province, to other farmworker populations in South Africa. This is due to the differences in the environmental and behavioural factors, influencing workers' exposure to solar UVR across various geographical areas of South Africa as well as different types of work carried out on different farms. Environmental factors such as latitude and altitude of an area influence the ambient solar UVR levels in that area and, consequently, the personal solar UVR exposure of outdoor workers. Salas *et al.* (2005) found that the type of crop that was being cultivated on a farm influenced

the work activities required from workers, which subsequently influenced the workers' exposure to solar UVR.

Limitation 4: Dosimetry is used to determine an individual's exposure to solar UVR. Different types of UVR dosimetry are available namely electronic, chemical and physical dosimetry. The polysulphone badges that were used in this study to measure solar UVR exposure is an example of chemical dosimetry that provide a total dose while electronic dosimetry is able to provide a more detailed measurement of exposure at specific time intervals, such as every hour of a work shift (King *et al*., 2015). Although the lighter weight of polysulphone badges made it possible to be easily attached to various anatomical positions, the use of electronic dosimeters would have provided more detail, for example regarding the time of day when outdoor workers were exposed to the highest solar UVR levels.

7.4. Future studies

Several opportunities for possible future studies have been identified following the completion of this study. These possible studies are:

Proposed study 1: Environmental factors such as varying altitude, latitude and topography as well as variation in the type of work activities that are required when cultivating different types of crops have been shown to influence personal solar UVR (Salas *et al*, 2005; Cahoon *et al*., 2013). Studies that assess the personal solar UVR exposure of farmworkers could be conducted in geographical areas located in other regions of South Africa than the area where the present study was conducted. In addition, further research is needed on farms in the Limpopo Province where crops such as tomatoes, citrus, mangoes and papayas are produced as well as farms where livestock are reared. The findings of these studies will provide a more comprehensive picture of the personal solar UVR exposure of the farming occupational group in the Limpopo Province and in South Africa as a whole. It will also assist in the design of effective photoprotective programmes, specific to each region.

Proposed study 2: The personal solar UVR exposure of outdoor workers in South Africa other than farmworkers also needs to be determined. There is a lack of research in this area with only a limited number of occupations being evaluated such as open parking security staff (Nkogatse *et al*., 2019) and factotums on

school grounds (Makgabutlane and Wright, 2015). Outdoor workers from other sectors such as construction workers, outdoor recreational workers such as lifeguards and game park rangers, postal delivery workers and teachers who coach outdoor sports activities should be included in future studies.

Proposed study 3: Tree species in Africa vary according to the type of leave canopy (Lucas *et a*l, 2016). This means that different trees may provide shade of varying quality. The investigation of the shade provided by different trees will give an accurate idea of the photoprotection provided by working under each type of tree.

Proposed study 4: As discussed in Section 8.3, electronic dosimetry provides a more detailed picture of solar UVR during the day. Further research using electronic dosimetry to measure personal solar UVR will be beneficial in identifying the pattern of solar UVR during the day as well as of what time of day workers received the highest levels of solar UVR. This type of information can be used to schedule workers' outdoor work activities for the time of day when ambient solar UVR levels are lower.

Proposed study 5: The knowledge and attitudes that workers have towards solar UVR have an influence on their use of photoprotective measures. Investigation of the knowledge that outdoor workers in various geographical areas and industries have regarding of solar UVR, how they are exposed to it and the correct use of photoprotective measures, will provide information on what should be included in solar UVR awareness programs.

Proposed study 6: Further research studies should include a more detailed investigation of the solar UVR levels that various body sites are exposed to during specific real life work activities found in industries such as construction workers. This will assist in identifying the specific activities that contribute to the exposure of certain body sites to potentially harmful solar UVR.

Proposed study 7: In this study, the terminology used in the questionnaires that determine self-reported or subjective skin colour was at times confusing for individuals with deeply-pigmented skin. For example, the concepts of

tanning or sunburn were not fully understood. The development of appropriate terminology in South African languages such as Tshivenda and Sepedi that can be used in questionnaires designed to determine self-reported skin colour, should be investigated.

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APPENDIX A: ETHICS CERTIFICATE

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Research Ethics Regulatory Committee
Tel: +27 18 299 4849
Email : Ethics@nwu.ac.za

ETHICS APPROVAL CERTIFICATE OF STUDY

Based on approval by **Health Research Ethics Committee (HREC)** on **01/03/2018**, the North-West University Research Ethics Regulatory Committee (NWU-RERC) hereby **approves** your study as indicated below. This implies that the NWU-RERC grants its permission that provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title: **The solar ultraviolet radiation exposure of outdoor farm workers in selected South African farm settings**

Study Leader/Supervisor: **Prof JL du Plessis**
Student: **K Linde**

Ethics number: N W U - 0 0 1 0 1 - 1 7 - A 1
Institution | Study Number | Year | Status

Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation

Application Type: Single Study
Commencement date: 01-03-2018 **Risk:** **Minimal**

Approval of the study is initially provided for a year, after which continuation of the study is dependent on receipt of the annual (or as otherwise stipulated) monitoring report and the concomitant issuing of a letter of continuation.

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following:

- *The study leader (principle investigator) must report in the prescribed format to the NWU-RERC via HREC:*
  - *annually (or as otherwise requested) on the monitoring of the study, and upon completion of the study*
  - *without any delay in case of any adverse event or incident (or any matter that interrupts sound ethical principles) during the course of the study.*
- *Annually a number of studies may be randomly selected for an external audit.*
- *The approval applies strictly to the proposal as stipulated in the application form. Should any changes to the proposal be deemed necessary during the course of the study, the study leader must apply for approval of these amendments at the HREC, prior to implementation. Should there be any deviations from the study proposal without the necessary approval of such amendments, the ethics approval is immediately and automatically forfeited.*
- *The date of approval indicates the first date that the study may be started.*
- *In the interest of ethical responsibility the NWU-RERC and HREC retains the right to:*
  - *request access to any information or data at any time during the course or after completion of the study;*
  - *to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process.*
  - *withdraw or postpone approval if:*
    - *any unethical principles or practices of the study are revealed or suspected,*
    - *it becomes apparent that any relevant information was withheld from the HREC or that information has been false or misrepresented,*
    - *the required amendments, annual (or otherwise stipulated) report and reporting of adverse events or incidents was not done in a timely manner and accurately,*
    - *new institutional rules, national legislation or international conventions deem it necessary.*
- *HREC can be contacted for further information or any report templates via Ethics-HRECApply@nwu.ac.za or 018 299 1206.*

The RERC would like to remain at your service as scientist and researcher, and wishes you well with your study. Please do not hesitate to contact the RERC or HREC for any further enquiries or requests for assistance.

Yours sincerely

Prof. Refilwe Phaswana-Mafuya
Chair NWU Research Ethics Regulatory Committee (RERC)

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Prof JL du Plessis
OHHRI

31 March 2019

Dear Prof du Plessis

FEEDBACK ON NWU-HREC ANNUAL MONITORING REPORT: NWU-00101-17-A1

We would like to thank you for submitting the annual monitoring report for your project entitled, ***"The solar ultraviolet radiation exposure of outdoor farm workers in selected South African farm settings"***, to the North-West University Health Research Ethics Committee (NWU-HREC) in a timely manner. Please find below the decision of the NWU-HREC regarding the continuation of your project.

Classification	Mark with X	Comment	
Clarification			
Completion (Final report)			
Suspended			
Continuation	X	**Date of next monitoring report:**	31 March 2020
Termination			

Should you have any further queries, please feel free to contact Ms Jamey Henry at your earliest convenience (E-mail: Ethics-HRECMonitoring@nwu.ac.za; Tel: 018 299 2266). We wish you well in your future endeavours.

Yours sincerely

Digitally signed by Wayne Towers
Date: 2019.03.22 09:51:45 +02'00'

Prof Wayne Towers
Chairperson: NWU-HREC

Digitally signed by Prof Minrie Greeff
Date: 2019.03.26 16:34:59 +02'00'

Prof Minrie Greeff
Head of Health Sciences Ethics Office for Research, Training and Support

Current details: (20536690) G:\My Drive\9. Research and Postgraduate Education\9.1.5.5 HREC Monitoring\NWU-00101-17-A1\9.1.5.5.4_Cont_NWU-00101-17-A1_31-03-2019.docm
31 March 2019

File reference: 9.1.5.5.4

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24 April 2020

Prof JL du Plessis
OHHRI

Dear Prof du Plessis

FEEDBACK ON NWU-HREC ANNUAL MONITORING REPORT: NWU-00101-17-A1

We would like to thank you for submitting the annual monitoring report for your project entitled, ***"The solar ultraviolet radiation exposure of outdoor farm workers in selected South African farm settings"***, to the North-West University Health Research Ethics Committee (NWU-HREC) in a timely manner. Please find below the decision of the NWU-HREC regarding the continuation of your project.

Classification	Mark with X	Comment	
Clarification			
Completion (Final report)			
Suspended			
Continuation	X	**Date of next monitoring report:**	31 March 2021
Termination			

Should you have any further queries, please feel free to contact Mr Buti Majola at your earliest convenience (E-mail: Ethics-HRECMonitoring@nwu.ac.za; Tel: 018 299 2197). We wish you well in your future endeavours.

Yours sincerely

Digitally signed by Prof Petra Bester
Date: 2020.04.27 15:13:38 +02'00'

Chairperson: NWU-HREC

Current details: (24355305) G:\My Drive\9. Research and Postgraduate Education\9.1.5.5 HREC Monitoring\NWU-00016-10-A1\9.1.5.5.4_Cont_NWU-00101-17-A1_31-03-2020.docm
31 March 2020
File reference: 9.1.5.5.4

APPENDIX B: PROOF OF SUBMISSION OF ARTICLES II, III AND IV TO SCIENTIFIC JOURNALS

Article II

12-Nov-2020

Dear Dr. Wright:

Your manuscript entitled "Low use of ocular sun protection among agricultural workers in South Africa: need for further research" has been successfully submitted online and is presently being given full consideration for publication in Photochemistry and Photobiology.

Your manuscript ID is PHP-2020-11-RN-0276.

Please mention this ID number in all future correspondence regarding your manuscript. If there are any changes in your street or e-mail address, please log in to ScholarOne Manuscripts at https://mc.manuscriptcentral.com/php and edit your user information as appropriate.

You can view the status of your manuscript at any time by checking your Author Center after logging in to https://mc.manuscriptcentral.com/php.

Thank you for submitting your manuscript to Photochemistry and Photobiology.

Sincerely,

Dr. Jean Cadet
Editor-in-Chief
Photochemistry and Photobiology

Article III

Dear Authors

Your manuscript entitled:

Ultraviolet radiation protection factor of clothing: South African farmworkers on a macadamia nut and avocado farm

has been received by Annals of Work Exposures and Health listing you as either the author or as a co-author, and has been assigned the number: ANNWEH-20-0326. The contact author is listed as Ms. Karlien Linde.

Thank you for submitting to this journal. We will email the contact author when an editorial decision has been made. Meanwhile the contact author can track the progress of the manuscript by looking in the Submitted Manuscripts section of their Author Centre in Manuscript Central.

If you are a co-author, please note that the contact author has made a statement of conflict of interest on your behalf, and has confirmed that this is original work not under consideration elsewhere. Our policy on who should be listed as an author is given at http://annhyg.oxfordjournals.org/content/51/8/651.full.pdf html. Although authors may have made different contributions, all authors are expected to accept responsibility for the whole paper. If you feel that you should not be listed as an author, please discuss with the contact author - this can be corrected later. If you do not recognise the paper at all, please contact annals@bohs.org as soon as possible.

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Thank you for your submission.

Yours sincerely,
Samantha Ponton
Editorial Assistant, Annals of Work Exposures and Health

Article IV

Dear Authors

Your manuscript entitled: Personal solar ultraviolet radiation exposure of farmworkers: seasonal and anatomical differences suggest prevention measures are required
has been received by Annals of Work Exposures and Health listing you as either the author or as a co-author, and has been assigned the number: ANNWEH-20-0318. The contact author is listed as Ms. Karlien Linde.

Thank you for submitting to this journal. We will email the contact author when an editorial decision has been made. Meanwhile the contact author can track the progress of the manuscript by looking in the Submitted Manuscripts section of their Author Centre in Manuscript Central.

If you are a co-author, please note that the contact author has made a statement of conflict of interest on your behalf, and has confirmed that this is original work not under consideration elsewhere. Our policy on who should be listed as an author is given at http://annhyg.oxfordjournals.org/content/51/8/651.full.pdf html. Although authors may have made different contributions, all authors are expected to accept responsibility for the whole paper. If you feel that you should not be listed as an author, please discuss with the contact author - this can be corrected later. If you do not recognise the paper at all, please contact annals@bohs.org as soon as possible.

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Thank you for your submission.

Yours sincerely,
Samantha Ponton
Editorial Assistant, Annals of Work Exposures and Health

APPENDIX C: DECLARATION OF LANGUAGE EDITING

WOORDE WAT WERK
WORKING WORDS

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5 December 2020

LANGUAGE EDITING STATEMENT

I, Jannetje Levina De Kock hereby declare that the thesis

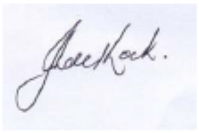
Skin colour, photoprotective measures and solar ultraviolet radiation exposure of workers on a macadamia nut and avocado farm

by
K. Linde

for submission to the NWU
in the Niche area Occupational Hygiene and Health Research Initiative (OHHRI)

- has been edited for language correctness and spelling.
- has been edited for consistency (repetition, long sentences, logical flow)

No changes have been made to the document's substance and structure (nature of academic content and argument in the discipline, chapter and section structure and headings, order and balance of content, referencing style and quality).



J L DE KOCK

APPENDIX D: QUESTIONNAIRES

Please note that not all data collected using the questionnaires is included in this thesis. The missing data will be analysed and submitted to a peer reviewed journal for publication at a later stage.

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January 2018

QUESTIONNAIRES ON SUN EXPOSURE OF OUTDOOR WORKERS

Dear Participant,

These questionnaires intend to measure the different aspects related to your exposure to the sun during work and off-duty time. These aspects include; your history of working outdoors, your practices/behaviour in terms of the protective measures you use, attitude and knowledge about the sun in general, as well as your Fitzpatrick skin phototype. The results of the questionnaires will help us to have a better understanding of gaps that exist as well as assist us in formulating recommendations towards protecting your health and overall well-being.

We will appreciate it if you could complete the questionnaire by following instructions given for each question or group of questions. As you complete the questionnaires, please do the following:

a) Read each question/statement carefully and mark the answer that is true for you,

b) Clearly indicate your answer by making a cross (X) in the box with the option that is true for you,

c) Answer as honestly as you possibly can,

d) Answer only one question at a time,

e) Answer all questions,

f) Ask for help whenever you need it and

g) Do not think too much about the questions.

If the person is not able to read the questionnaire then a researcher will help the participant to fill in the questionnaire by reading the questions to him/her and writing down the answers.

Yours sincerely

Ms K Linde

karlien.linde@gmail.com

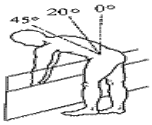
Participant code: _____

A: Participant questionnaire on the amount of sun received and practices during

This questionnaire contains 5 parts and a total of 37 questions or statements. The aim of this questionnaire is to determine your history of outdoor work, practices and training you may have received. Please read each one carefully and answer as truthfully as you possibly can. Instructions are given for each question or a group of questions to assist you with answering them.

PART 1: BIOGRAPHICAL DATA/ PERSONAL INFORMATION. Mark the correct box with and X.								
Work site:					*Date:*			
Gender	Male		Female		*Age (Years)*			
Ethnicity	White		Black		Indian		Coloured	
In which job category are you?								
What is your highest level of education?			No schooling		*Other:*			
Do you know your HIV status?								
Negative		Positive		I do not know		I do not want to tell		

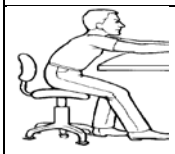
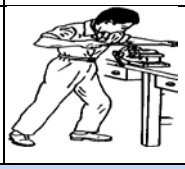
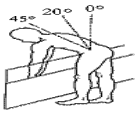
PART 2: THIS SECTION IS ABOUT THE WORK (JOB) YOU DID BEFORE YOU BEFORE YOU STARTED WORKING ON THE FARM. Make a cross (X) in the box with the answer that is true for you.		
A1) Did the work you did before you started working at the farm involve working outside in the sun?	No	Yes
If your answer to A1 above is Yes, then continue with Question A2 to A7, otherwise go to Question A8.		
A2) How long (in years or months) did you work in the past outdoor job?		
A3) How many days of the week did you work in your previous outdoor job?		
A4) *How many hours a day did you work outside in your previous job?*		

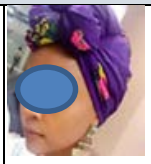
A5) Which body position(s) did you adopt the most in your previous job? (Mark with an X all that are true for you)				
Sitting	Standing	Lying down	Crouching	Bending forward
				

A6) Did you receive sun safety education and training in your previous job? If your answer is Yes, indicate the number of times you received training			
No	Yes	Once	
		Two or more times	

A7) If you received sun safety education and training, which of the following aspects did your training cover in your previous outdoor job? (Make a cross (X) on all that are true for you)				
How to use sunblock	Importance of covering your skin with clothes that have long sleeves	Importance of eye protection	Importance of staying in the shade (under a tree or shelter)	Importance of skin checks

PART 3: THIS SECTION IS ABOUT THE JOB YOU ARE DOING NOW AT THE FARM. *Make a cross (X) on the box with the answer that is true for you.*	
A8) How long (in years or months) have you been in the outdoor job you hold now?	
A9) How many days a week do you work in the outdoor job you hold now?	
A10) How many hours a day do you work outside in the outdoor job you hold now?	

For question A11 to A15 you are required to make a cross (X) in the box with the answer that is true for you.				
A11) Which body positions do you adopt the most in the job you hold now? (Make a (X) cross on all that are true for you)				
Sitting	Standing	Lying down	Crouching	Bending forward
				
A12) Do you use welding equipment during any of your work activities in the job you hold now?				
Never	Sometimes	Always		
A13) Did you receive sun safety education and training in job you hold now? If your answer is Yes, please indicate the number of times you received training				
No	Yes	Once		
		Two or more times		
If you did not receive training, skip A14.				
A14) if you did receive training, which of the following aspects did the training in your current job cover? (tick all applicable)				
How to use sunblock creams	Importance of covering your skin with long sleeved clothes	Importance of eye-protection	Importance of staying in the shade whenever possible	Importance of skin checks	Health effects of prolonged exposure to the sun
A15) Do you work in the shade (under a tree or shelter where it is available) in the job you hold now?				*No*	*Yes*
A16) If your answer to A15 is yes, please write down the number of hours you work in the shade every day in the job you hold now?					

PART 4: THIS SECTION IS ABOUT YOUR PERSONAL PRACTICES (OR YOUR BEHAVIOUR) WHEN YOU ARE AT WORK. ***Make a cross (X) on the box with the answer that is true for you.***			
A17) In which type of area do you spend your breaks (lunch and tea times)?			
Sunny (Not covered)	Shady (Covered)	Semi-shady (Tree)	I move around between different types of areas
A18) Do you apply sunblock while working in the sun?			
Never	Sometimes	Always	
A19) If you do apply sunscreen, on which parts of your body do you apply sunscreen while in the sun? Please choose all are true for you.			
Face	Neck	Arms	Legs
A20) How often do you reapply sunscreen when outdoors during working hours?			
Never	Every 5 hours	Every 2 hours	Every 1 hour	More than once per hour
A21) How often do you wear a hat when outdoors during working hours?			
Never	Sometimes	Always	
If your answer to A21 above is Never skip A22.			
A22) Make a cross in the box with the type(s) of hat you wear when outdoors during working hours? (Mark all that are true for you)			
							

A23) Which type of clothes do you wear most of the time when you are at work? (Mark all that are true for you with an X)						
T-shirt		Shirt		Coveralls		
Short sleeve	Long sleeve	Short sleeve	Long sleeve	No sleeves, long pants	Short sleeves, long pants	Long sleeves, long pants
						

A24) How often would you wear less clothing so that you are able to get some sun on your skin while at work?		
Never	Sometimes	Always

A25) How often do you wear eye-protection (sunglasses) when outside during working hours?		
Never	Sometimes	Always

If your answer to A25 is Never, then skip A26.

A26) Mark the type of eye-protection you wear when you are at work.				
Non-Prescription sunglasses with UVA and UVB lenses	Prescription sunglasses with tinted lenses	Prescription sunglasses with plain lenses (no tinting)	Goggles	Wrap-around goggles
				

PART 5: THIS SECTION IS ABOUT YOUR PERSONAL PRACTICES (YOUR BEHAVIOUR) DURING OFF-DUTY TIME. ***Make a cross (X) on the box with the answer that is true for you.***

A27) How many hours do you spend in the sun per day during your off-duty time?	

A28) Do you apply sunblock (sunscreen) when outdoors during your off-duty time?		
Never	Sometimes	Always

A290) On which parts of your body do you apply sunscreen when outdoors during your off-duty time? Please mark all that apply to you with an X.			
Face	Neck	Arms	Legs

A30) How often do you reapply your sunblock (sunscreen) when outdoors during your off-duty time?		
Never	Sometimes	Always

A31) If you do reapply sunblock (sunscreen), how many hours do you wait before you reapply during your off-duty time?	

A32) *What is the Sun Protection Factor (SPF) of the sunblock (sunscreen) you use during your off-duty time?*			
I do not know	*15*	*Greater than 30*	*Greater than 50*

A33) Which type of clothing do you wear when outdoors during your off-duty time? Mark all that are true for you with an X

T-shirt		Shirt		Coveralls		
Short sleeve	Long sleeve	Short sleeve	Long sleeve	Long sleeves, long pants	No sleeves, long pants	Short sleeves, long pants
						

A34) Which type(s) of hat(s) do you wear most of the time during your off-duty time? Mark all that are true for you with an X

Never								
								

A36) How often do you wear eye-protection (sunglasses) when outdoors in your off-duty time?		
Never	Sometimes	Always

A37) if you wear eye protection, which type of eye-protection do you wear when outdoors in your off-duty time

Non-Prescription sunglasses with UVA and UVB and tinted lenses	Non-prescription sunglasses with UVA and UVB lenses	Prescription lenses with no tinting	Goggles	Wrap-around goggles
				
A38) Do you use any product or substance to lighten your skin?				
Never	Rarely	Sometimes	Usually	Always
A39) If you have ever used one more product or substance to lighten your skin, please name all the products or substances				

B: Knowledge and attitudes of outdoor workers regarding the sun

This questionnaire, containing 4 parts and 36 questions/statements, aims to determine how much you know about the sun and your attitudes towards the sun. Please read each question/statement carefully and mark the box with the answer that is true for you.

PART 1: THIS PART IS ABOUT YOUR GENERAL KNOWLEDGE ABOUT THE SUN AND ITS HEALTH EFFECTS. ***Make a cross (X) on the box with the answer that is true for you.***			
B1) Have you received any information about the sun and its health effects?	No	Yes	
B2) Where did you receive the information about the sun and its health effects? (Write down your answer)			
B3) Do you know what ultraviolet radiation is?	No	Yes	
B4) Do you know the meaning of the Ultraviolet index (UVI)?	No	Yes	
B5) What time of the day is the sun the hottest? (Mark the first box if you do not know or write down your answer in the second box)			
I do not know	Answer:		
B6) It is good to spend a little time in the sun every day	No	Yes	I do not know
B7) Spending a lot of time in the sun is the most important risk factor for skin cancer	No	Yes	I do not know
B8) How is your health affected when you work in the sun for a long time? (Mark the first box if you do not know or write down your answer in the second box)			
I don't know	Answer:		

B9) Do people with darker skin colour suffer from health effects caused by the sun?		
No	Yes	I do not know
B10) Do people with darker skin burn as easily as people with lighter skin?		
No	Yes	I do not know
B11) When the sun burns you skin it causes a permanent damage.		
No	*Yes*	
PART 2: THIS PART IS ABOUT YOUR KNOWLEDGE OF THE WAYS OF PROTECTING YOURSELF AGAINST THE SUN. ***Make a cross (X) on the box with the answer that is true for you.***		
B12) Do you know what a sunblock's (sunscreen's) sun protection factor (SPF) means?		
No	Yes	I have heard of it but I do not know what it means
B13) Do people with lighter colour skin have to use sunblock (sunscreen)?		
No	Yes	I do not know
B14) Do people with dark skin colour have to use sunblock (sunscreen)?		
No	Yes	I do not know
B15) What type of clothing prevents more of the sun from reaching the skin surface?		
Lighter coloured clothing	Darker coloured clothing	I do not know
PART 3: THIS PART IS ABOUT YOUR ATTITUDES WHEN SPENDING TIME IN THE SUN. ***Make a cross (X) on the box with the answer that is true for you.***		
B16) Do you look at the ultraviolet index (UVI) when planning to go outside?	No	Yes
B17) Would you change your plans to go outside if you knew that the ultra violet index (UVI) level was?	No	Yes
B18) Do you worry about sun when working outside?	No	Yes
B19) I spend too much time in the sun.	No	Yes

B20) I stay for a long time in the sun to darken my skin.	No	Yes
B21) Somebody that has a darker skin is more attractive.	No	Yes
B22) I enjoy spending time in the sun.	No	Yes

B23) I think I am at risk of skin cancer.		
No	Yes	I do not know

PART 4: THIS PART IS ABOUT YOUR ATTITUDES TOWARDS WAYS OF PROTECTING YOURSELF AGAINST THE SUN. ***Make a cross (X) on the box with the answer that is true for you.***

B24) Protecting yourself against the sun is important when you are driving or in a car/taxi as a passenger.	No	Yes

B25) It is important to work or stand in the shade (where there is no sun such as under a tree or shelter when it is available) when it is hot.		
No	Yes	I do not know

If your answer to B25 is Yes, then answer B26 below

B26) Why do you work in the shade when it is available (where there is no sun such as under a tree, shelter or indoor areas)?		
Somebody tells me to work there	It is cooler	It protects me from the sun

B27) It is important to protect your skin with clothes that have long sleeves		
No	Yes	I do not know

If your answer to B27 is Yes, then answer B28 below

B28) Why do you wear clothes with long sleeves when working outside in the sun?		
Somebody tells me to wear clothes with long sleeves	I look good in long sleeved clothing	It protects my skin from the sun

B29) It is important to wear sunglasses to protect my eyes from the sun		
No	Yes	I do not know

If your answer to B29 is Yes, then answer B30 below, otherwise go to B31.

B30) Why do you wear sunglasses when you are outside in the sun?		
Somebody tells me to wear it	I look good in sunglasses	It protects my eyes from the sun
B31) It is important to wear a hat when you are outside in the sun		
No	Yes	I do not know
If your answer to B31 is Yes, then answer B32 below		
B32) Why do you wear a hat when you are outside in the sun?		
Somebody tells me to wear it	I look good in a hat	It protects my head and face from the sun
B33) It is important to apply sunblock whenever you go outside in the sun.		
No	Yes	I do not know
If your answer to B33 is Yes, then answer B34 below. If your answer to B33 is No or I do not know, then go to B35 and B36.		
B34) You apply sunblock when outside in the sun because.....(Mark the answer that is true for you)		
Somebody tells me to apply sunblock	Sunblock protects my skin from being burned by the sun.	
B35) Sunblock is too expensive	No	Yes
B36) I do not have time to apply sunblock	No	Yes

Part 1: THIS PART IS ABOUT Your Physical features Make a cross (X) on the box with the answer that is true for you.				
C1. What is your eye colour?				
Green	Blue	Hazel/light brown	Dark brown	Black
C2. What is your natural hair colour?				
Red	Blonde	Dark blonde/light brown	Dark brown	Black
C3.Which of the following is the closest to the colour of your skin that is not exposed to sun?				
				 
C4) How many freckles to do you have on your unexposed skin				
None	One or two	Few	Several	Many
part 2:THIS PART IS ABOUT THE REACTION of YOUR skin to sun exposure Make a cross (X) on the box with the answer that is true for you.				
C5) What happens to your skin if you spend a lot of time in the sun?				
Nothing	My skin turns brown/ I tan	My skin turns red, but it is not painful	My skin turn red and it is painful	I burn blisters and it is painful
C6) How many freckles do you have on your skin that is not exposed to sun?				
None	Few	Average	Several	Many

C7) Do you turn brown/darker or tan after spending a lot of time in the sun?				
Never	Rarely	Sometimes	Usually	Always
C8) .How brown/darker does your skin get when spending time in the sun?				
Does not get brown/tan	Light tan	Medium tan	Dark tan	Deep dark brown
C9) How long does your brown /darker colour/ or tan last after spending a lot of time in the sun?				
No time. I do not tan	For a few days	For a few weeks	For a few months	For longer than a few months