Quality attributes of pomegranate fruit and co-products relevant to processing and nutrition

by

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Declaration

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SUMMARY

Pomegranate fruit, owing to its health benefits, has served several important applications in industrial processing and nutrition. However, knowledge of the physico-chemical and textural properties of the fruit relevant to processing and nutrition remains critical. Presently, the South African pomegranate industry has great concerns on key issues governing pomegranate fruit processing. These issues are centered on understanding how pomegranate fruit properties influence prospect for value addition, processing and nutrition; what extent do cultivar differences influence the ease of processing and suitability as a raw material in food processing; and how to classify pomegranates based on their potential as source of raw materials for health-promoting compounds. Based on these, the overall aim of the study was to add value to commercially cultivated pomegranate ('Wonderful', 'Acco' and 'Herskovitz') in South Africa by evaluating their physical, textural and chemical properties, including the nutritional and mineral compositions, and quality attributes and functional properties of the kernels and oil constituents of these cultivars with emphasis on processing.

Investigation of the physical properties of 'Wonderful', 'Acco' and 'Herskovitz' showed no significant differences in whole fruit weight, length, diameter, geometric mean diameter, surface area and volume of oblate spheroid among the cultivars. However, Wonderful and Herskovitz fruit cultivars had the highest (61.62%) and lowest (56.98%) edible portion, respectively. In addition, the arils of 'Acco' yielded the highest juice volume (74.05 mL/100 g arils i.e. 74.05%). Furthermore, juice extracted from 'Wonderful' contained the highest total soluble solids (15.93°Brix) while 'Herskovitz' fruit juice was characterised by high titratable acidity (1.32% citric acid). The textural properties in terms of maximum forces to cut, puncture and compress the fruit, distinguished 'Wonderful' whole fruit from the other cultivars. These textural tests characterised Wonderful cultivar as the hardest and therefore would require higher mechanical energy than the other cultivars during processing.

The physical and textural properties of fresh and dried arils and kernels relevant to processing and nutrition were also investigated. As expected, the loss of moisture in fresh arils and kernels resulted in a significant reduction in weight and lineal dimensions. However, kernel index, shape index as well as compressibility characteristics of both arils and kernels increased for the cultivars after drying. From value-addition viewpoint, the kernels of Acco cultivar contained the highest oil yield (27.39%), proteins (18.73%), energy (1655.60 kJ/100 g), moisture (0.24%), ash (3.55%) and dietary minerals. On the other hand, kernels of 'Wonderful' and 'Herskovitz' were rich in carbohydrate (30.65%) and dietary fibre (36.48%), respectively. In addition, dietary mineral profiling of pomegranate kernel was in the order of Nitrogen (2453.00 – 3047.00 mg/100g) >

Potassium (846.67 – 1646.00 mg/100g) > Phosphorus (380.33 – 500.67 mg/100g) > Magnesium (144.33 – 204.67 mg/100g) > Calcium (138.33 – 152.67 mg/100g) > Sodium (10.67 – 21.55 mg/100g) > Iron (5.28 – 5.72 mg/100g) > Zinc (2.91 – 3.94 mg/100g) > Copper (1.89 – 2.58 mg/100g) > Manganese (1.40 – 1.99 mg/100g) > Boron (0.96 – 1.82 mg/100g). These amounts are within the Recommended Daily Allowance (RDA) proposed by European Union and United States of America. These findings may therefore help processors and nutritionists to improve food formulations with pomegranate kernels.

The study was further extended with special interest on pomegranate kernel oil (PKO). The yield of PKO ranged between 16.59 – 27.39% and were in the order ‘Acco’ > ‘Herskovitz’ > ‘Wonderful’, regardless of extraction solvent. Acetone extracted PKO with light yellow colour and also, with high amounts of phenolics, tocol, α- and γ-linolenic acids and *para*-anisidine value. However, among the cultivars, PKO of ‘Herskovitz’ had the highest *para*-anisidine value suggesting its weak resistance to oxidation. Punicic acid, a unique conjugated linolenic acid in PKO, ranged between 59.90 – 69.85% and were in the order of petroleum ether > *n*-hexane > acetone. In addition, the investigated PKO exhibited high (89.50 – 91.60%) radical scavenging activity, regardless of cultivar and extraction solvent. In terms of oil stability, storage temperature and duration affected properties of PKO. In comparison with oil stored at 25°C, a remarkable reduction in punicic acid and increase in α- and γ-linolenic acids were observed in PKO stored at 60°C. This study showed that PKO of ‘Wonderful’, ‘Acco’ and ‘Herskovitz’ could potentially serve as good source of bioactive oil.

Overall, this study presents scientific background on how pomegranate cultivars could influence the ease of processing, and their suitability as sources of raw materials for health-promoting compounds in nutraceutical industries.

OPSOMMING

Granate, met sy gesondheidsvoordele, het belangrike toepassings in die industriele proseseering en voedingstowwe. Alhoewel die kennis van die fisio-chemiese en tekstuur eienskappe van die relevante vrugte relevant is tot die nutriente, bly die na-oes prosseseering steeds krieties. Tans, die Suid-Afrikaanse granaat bedryf het 'n groot kommer oor belangrike kwessies regerende granaatboom vrugte verwerking. Hierdie kwessies is gesentreer op die begrip van hoe granaatboom vrugte eienskappe beïnvloed vooruitsig vir waardetoevoeging, verwerking en voeding; watter mate stem kultivar verskille beïnvloed die gemak van die verwerking en geskiktheid as 'n rou materiaal in die voedsel verwerking; en hoe om granate te klassifiseer op grond van hul potensiaal as bron van grondstowwe vir gesondheidsbevorderende verbindings. Gebasseer op die bogenoemde is die doel van die studie om waarde by te voeg tot komersiële gekultiveerde granate (‘Wonderful’, ‘Acco’ en ‘Herskovitz’) in Suid-Afrika deur die fisiese, tekstuur en chemise aspekte, insluitend die nutrient en mineral samestellings, kwaliteit en funksionele eienskappe van die kern en olie samestellings van die kultivars met beklemtoning om prossesseering te evalueer.

Met ondersoek van die fisieke eienskappe van die ‘Wonderful’, ‘Acco’ en ‘Herskovitz’ het daar geen beduidende verskille in die vrug se gewig, lengte, diameter, geometriese gemiddelde diameter, oppervlak area of volume van die sfere voorgekom nie. Alhoewel, die ‘Wonderful’ en ‘Herskovitz’ granaat kultivars het die hoogste (61.62%) en die laagste (56.98%) eetbare porsie. Daareenbenewens het die saad van die ‘Acco’ ekstraksie die hoogste volume sap (75.05 mL/100 g m.a.w. 74.05%) gelewer. Verde het die sap ekstraksie van die ‘Wonderful’ granaat die hoogdte totaal oplosbare soliede bevat (15.93°Brix) terwyl ‘Herskovotz’ vrugtesap geklasifiseer is deur sy hoë titreerbare suurheid (1.32% sitroensuur). Die tekstuur eienskappe in term van die maksimum kragte om die granaat te sny, kneus en die vrugte te prosseseer het veroorsaak dat dit die ‘Wonderful’ vrug van die ander kultivars skei. Hierdie tekstuur toetse het die ‘Wonderful’ kultivar geklasifiseer as die hardste vrug en benodig meer meganiese energie as die ander kultivars gedurende prosseseering.

Die fisiese en tekstuur eienskappe van die vars en gedroogde saad en kern relevant tot die proseseering en nutriente was ook geondersoek. Soos verwag het die verlies van vog in vars saad en kern ‘n beduidende verlies in massa en liniëre dimensies veroorsaak. Alhoewel, die kern en vorm indeks asook die kompressie eienskappe van beide saad het toegeneem vir elke kultivars na drooging. Van ‘n waarde toevoeging oogpunt het die kern van die ‘Acco’ kultivar die hoogste olie opberengs gelewer (27.39%), proteïene (18.73%), energie (1655.60 kJ/100g), vog (0.24%) en minerale. Aan die ander kant, die kern van die ‘Wonderful’ en ‘Herskovitz’ was ryk in die koolhidrate (30.65%) en vesel (36.48%). Die klasifiseering van die granaatkern was gedoen met die hulp van Stikstof (2453.00 – 3047.00 mg/100g) > Kalium (846.67 – 1646.00 mg/100g) > Fosfor (380.33 – 500.67 mg/100g) > Magnesium (144.33 – 204.67 mg/100g) > Kalsium (138.33 – 152.67 mg/100g) > Natrium (10.67 – 21.55 mg/100g) > Yster (5.28 – 5.72 mg/100g) > Sink (2.91 – 3.94 mg/100g) > Koper (1.89 – 2.58 mg/100g) > Mangaan (1.40 – 1.99 mg/100g) > Boron (0.96 – 1.82 mg/100g). Hierdie hoeveelhede is binne die voorgeskere RDA (Recommended Daily Allowance) voorgeskryf deur die Europese Unie van die Verenigde State van Amerika. Hierdie bevindings kan dus proseseerders en dietkundiges help om die voedsel formulasies van die granaat kern te verbeter.

Die studie was verder uitgebrei met spesiale aandag op die granaat kern olie (GKO). Die opberengs van die GKO het gevarieer tussen 16.59 – 27.39% en in die volgorde ‘Acco’ > ‘Herskovitz’ > ‘Wonderful’, afgesien van die ekstraksie oplosmiddel. Asetoon geekstraeerde GKO met ‘n ligte geel kleur met hoë hoeveelhede van fenoliese verbindings, tacol, α- en γ- linoleensuur en para anisidien waarde het gely tot swak weerstand tot oksidasie. Punicic suur, ‘n unieke gekonjugeerde linoleensuur in GKO het gevarieer tussen 59.90 – 69.85% en was in die orde: petroleum-eter > n-heksaan > asetoon. Die ondersoekte GKO het hoë (89.50 – 91.60%) radikale soekende aktiwiteit afgesien van die kultivar en ekstraksie oplosmiddel. In terme van olie stabiliteit, stoor temperatuur en tyd geaffekteer deur die eienskappe van GKO. In vergelyking met die olie wat gestoor word teen 25°C, ‘n merkwaardige afname in punicic suur en ‘n toename in α- en γ-linoleensuur was geobserveer in GKO wat gestoor is teen ‘n temperatuur van 60°C. Hierdie studie het getoon dat die ‘Wonderful’, ‘Acco’ en ‘Herskovitz’ potensieel kan dien as goeie bron van bioaktiewe olie.

Hierdie studie verteenwoordig algehele wetenskaplike agtergrond oor hoe om die granaat kultivars te gebruik om proseseering te vergemaklik en die geskiktheid van die rou material vir gesondheid bevorderingde stowwe in die voeding industrië.

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Chapter 1

General introduction

GENERAL INTRODUCTION

1. Background

The increasing economic importance of agricultural produce together with the advancement of modern technological knowhow for their postharvest handling, processing, preservation and distribution, as well as marketing and utilization calls for an in-depth knowledge of all physico-chemical, textural and nutritional properties of the produce (Mohsenin, 1970). This therefore means that all farm produce, with special emphasis on fruits, tend to have unique properties, even within cultivars of the same species (Naderiboldaji *et al.*, 2008). These unique properties help determine the quality of fruit and correlations in changes that could occur in fruit properties hence, making quality control and processing easier (Muskovics *et al.*, 2006). According to Arshad *et al.* (2014), the individual properties of a fruit are inherently connected in defining their acceptability for stakeholders that include growers, processors and consumers. In recent years, newly improved trends in processing with enhanced concern over fruit quality and safety have emerged greatly (Ahangari & Sargolzaei, 2012). Furthermore, best postharvest handling and industrial processing practices of fruits has led to the achievement of better nutrients retention and quality of fresh produce at the consumer level and has also caused a reduction in quality heterogeneity in the respective raw materials for processed finished products (Arshad *et al.*, 2014).

Pomegranate belongs to the family *Punicaceae* with the genus *Punica*, because the best fruit was found in Carthage (also called Punica by the Romans) hence the scientific name *Punica granatum* (Akpinar bayizit *et al*., 2012; Mir *et al*., 2012). Although, pomegranate is native to Iran, Afghanistan, China and India (Ismail *et al.*, 2012), several different cultivars are currently widely cultivated in other parts of the world including South Africa (Morton, 1987; Citrogold, 2011). Pomegranate is a mildly temperate to subtropical plant (Morton, 1987). It thrives best in winter and under less humid conditions when proper irrigation facilities are put in place. Presently, several processing industries have great uses of pomegranate in deriving important commercial products. For instance, the food and beverage industries use the fruit fractions as essential ingredients in functional foods and dietary supplements (Seeram *et al.*, 2006; Viuda-Martos *et al.*, 2010a). Pharmaceutical and cosmeceutical industries have widely explored pomegranate in developing therapeutic formulations and improving skin health (Kostick *et al.*, 2007; Viuda-Martos *et al.*, 2010b). Pomegranate has also been extensively used in dye industries in the commercial production of dye and ink (Ergun & Ergun, 2009; Bruni *et al.*, 2011; Teixeira *et al.*, 2013).

The health benefit in association to the consumption of pomegranate is fascinating to researchers (Seeram *et al.*, 2006; Wang *et al.*, 2010). This global awareness has resulted in greater demand and increased production of pomegranate over the past decade (Seeram *et al.*, 2006; Citrogold, 2011; POMASA, 2012). Whilst the South African pomegranate industry aims at increasing pomegranate yield and quality in meeting export demands, the interest in consumption by its local market is rising steadily (Kotzé, 2012; Hortgro, 2014; POMASA, 2012). Pomegranate fruit cultivars can be classified based on their taste perceptibility or season of harvesting. Classes of taste include sweet, sweet-sour and sour whereas season of harvesting comprises early harvest, mid-harvest and late harvest (Citrogold, 2011; POMASA, 2012; Fawole, 2013). The fruit could either be consumed fresh or after it is processed and bottled or converted into other forms such as jellies, jams, food colourings and flavourings (Melgarejo *et al.*,2000; Seeram *et al.*, 2006; Aarabi *et al.*, 2008; Ergun & Ergun, 2009; Mousavinejad *et al.*, 2009). In addition, the fruit is nutritious, contains lower calories and high fibre content (Al-Maiman & Ahmad, 2002; Wang *et al.*, 2004; Fadavi *et al.*, 2006; Cassell, 2012; Fawole *et al.*, 2012; Hellen *et al.*, 2014).

Nonetheless, unfavourable preharvest conditions and poor postharvest handling, starting from the production units on the farm to consumers, tend to impart poor quality attributes to pomegranate fruit, resulting in fruit susceptibility to decay, weight loss and postharvest waste (Opara *et al.*, 2015; Mphalele, 2016). Maintenance of fruit quality during postharvest handling, storage, processing and distribution are dependent on the understanding of all fruit properties such as fruit maturity, size and shape; fruit dimensions and density; compressibility, cutting strength and puncture resistance; and the degree of fruit resistance to oxidation and other forms of spoilage (Mohsenin, 1970; Stroshine, 1998; Naderiboldaji *et al.*, 2008). For instance, the length, diameter and other derived properties of fruit have enabled processors in constructing aperture sizes and adjusting spacing of slicing discs during processing (Naderiboldaji *et al.*, 2008). Also, knowledge of fruit density has helped processors in modelling fruit flow rate and designing transport systems (Stroshine, 1998). As an implication, processing fruit without considering their inherent properties could lead to postharvest losses (Mohsenin, 1970; Stroshine, 1998; Sirisomboon *et al.*, 2007; Athmaselvi *et al.*, 2014).

In view of this, the physical, textural and chemical properties of three commercial pomegranate fruit cultivars (‘Wonderful’, ‘Acco’ and ‘Herskovitz’) grown in South Africa would be studied with relevance to processing (Fig. 1). Secondly, the nutritional and mineral compositions of the often-discarded kernels, as well as the quality attributes and functional properties of the kernel oil would also be examined with the aim of finding new ways for utilizing these pomegranate fruit fractions or co-products.

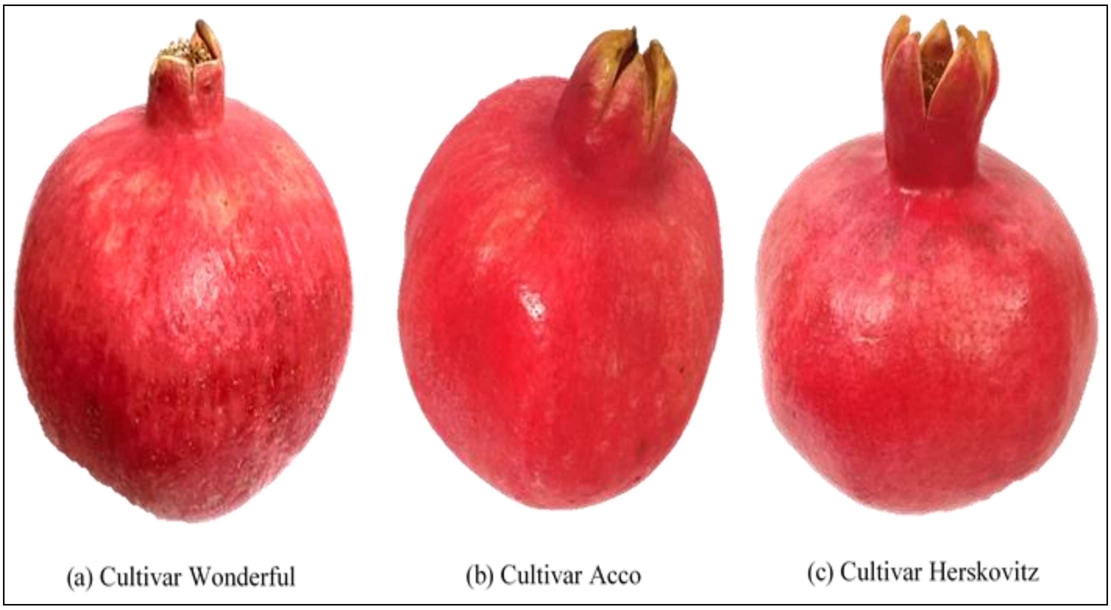

Fig. 1. Commercially grown pomegranate fruit cultivars in South Africa

1.1. Research statement

In recent years, consumers have shown a significant interest in pomegranate fruits due to their health implications (Hess-Pierce & Kader, 2003; Holland & Bar-Yaʿakov, 2008; Opara *et al.*, 2009; Viuda-Martos *et al.*, 2010b; Hellen *et al.*, 2014). This increasing global interest has boosted pomegranate production and processing and thus, spurring the need of many scientific studies in minimizing postharvest losses, maintaining industrial high throughput and better retaining product quality. Following this, knowledge of the physico-chemical and textural properties of pomegranate fruit and co-products relevant to processing and nutrition remains critical.

The physical and textural properties of pomegranate fruit and co-products may be important in understanding the physical regulations that govern these agricultural materials such that processing equipment and processes can be fabricated and effectively optimised in achieving the highest quality of end products whilst minimising fruit losses. Simultaneously, such knowledge, from an energy stand-point, can be used to precisely determine the best techniques in yielding products of interest from pomegranate fruit. Knowledge of the chemical properties of pomegranate fruit co-products may be useful in addressing their stability against oxidation and spoilage. Also, knowledge of the phytochemical composition and radical scavenging capacities of pomegranate fruit co-products may lead to the formulations of easily accessible functional foods with potent bioactive properties. Notwithstanding, the nutritional and mineral contents of pomegranate fruit can serve a greater purpose in nutrition. Furthermore, this study aims at making every harvest count by finding new courses of proving how pomegranate kernels and oil constituents may serve as a component of several bioactive ingredients of functional foods and pharmaceutical or cosmeceutical products.

1.2. Research question

The following questions are common issues confronting pomegranate producers and postharvest handlers and processors in South Africa:

i. How do fruit properties influence prospect for value addition, processing and nutrition?
ii. To what extent do cultivars differences influence the ease of processing and suitability as a raw material in food processing?
iii. Is it possible to classify pomegranates based on their potential as source of raw materials for health-promoting compounds?

2. Research aim and objectives

2.1. Research aim

The overall aim of the present research was to add value to pomegranate fruit grown in South Africa by evaluating some selected physical, textural and chemical properties, including the nutritional and mineral compositions of pomegranate kernels and the quality attributes, functional properties and chemical compositions of pomegranate oil with emphasis on industrial processing and nutrition.

2.2. Research objectives

The objectives of the study were to:

i. Investigate the physical and textural quality attributes of pomegranate whole fruit, arils and kernels
ii. Investigate the drying kinetics and drying dependent physico-textural properties of both the arils and kernels, as well as proximate and elemental compositions of the kernels
iii. Determine the quality attributes, functional properties and chemical compositions of pomegranate kernel oil
iv. Classify the examined pomegranate fruit cultivars based on their potential as source of raw materials in processing and their suitability in nutrition

3. Significance of research

Despite the importance of the study subject area, intensive research data on the properties of pomegranate fruit were only made available in recent years. As an implication, the present study seeks to highlight the importance of several inherent properties of pomegranate fruit for industrial scale processing. Thus, knowledge of these properties would constitute important engineering data that can be of great use in designing processing equipment, accessories and controls. The applications of such knowledge may also be extended in analysing and determining the efficiency of postharvest processing equipment and operations. In addition, in-depth understanding of the chemical compositions, stability and functional properties of pomegranate co-products could lead to development of new consumer products of pomegranate fruit origin.

4. Thesis structure

This thesis is organized into six chapters:

- Chapter 1: introduces the study, the research aim and objectives, the rationale behind the study and the impact of the research.
- Chapter 2: constitutes a descriptive review on existing research data on pomegranate fruit properties and their potential applications in processing and nutrition.
- Chapter 3: evaluates pomegranate fruit physico-chemical and textural properties of whole fruit and arils in a quest to characterize the investigated commercially grown pomegranate fruit cultivars.
- Chapter 4: focuses on processing of pomegranate arils and kernels by investigating their drying-dependent physical and textural properties. In addition, value adding potential of pomegranate fruit in terms of proximate and elemental compositions of kernels is further explored.
- Chapter 5: investigates the effects of extraction solvents on the quality attributes, functional properties and stability of pomegranate kernel oil.
- Chapter 6: highlights the significance of the research findings and their possible practical applications to value-adding potential of pomegranate fruit.

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Chapter 2

Quality attributes and functional properties of pomegranate fruit (*Punica granatum* L.) relevant to processing and nutrition – a review

QUALITY ATTRIBUTES AND FUNCTIONAL PROPERTIES OF POMEGRANATE FRUIT (*PUNICA GRANATUM* L.) RELEVANT TO PROCESSING AND NUTRITION – A REVIEW

Abstract

Pomegranate is widely cultivated in several parts of the world. Agricultural practices that goes hand in hand with the use of modern technology in harvesting, handling and processing pomegranate fruit often lead to postharvest losses in pomegranate industries. An investigation of the quality attributes and functional properties of pomegranate fruit and their practical applications in processing and nutrition is necessary to make all fruit harvest count. This review presents an overview on the physico-chemical, textural and functional properties of pomegranate fruit and co-products and their applications in processing and nutrition. Furthermore, some of these properties of pomegranate cultivars grown in different regions were compared and the corresponding unique qualities of the fruit highlighted.

Keywords: Co-product, Cultivar, Physico-chemical, Phytochemicals, Postharvest

1. Introduction

Modern agricultural practices have necessitated the use technological applications in postharvest handling, grading, storage and processing of agricultural produce by making use of the physical, textural, thermal, electrical and optical properties of the agricultural produce (Mohsenin, 1970; Ahangari & Sargolzaei, 2012). Despite an ever-increasing technological knowhow of these agricultural applications, a significant higher number of fruit and vegetables are lost during postharvest handling and processing. In addition, several natural sources of important bioactive nutrients and phytochemicals are underutilised (Kýralan *et al*., 2009; Modaresi *et al*., 2011; De Melo *et al*., 2014). Knowledge of fruit inherent properties should be evaluated, prioritised and considered essential in designing handling and processing equipment and structures (Mohsenin, 1970). Such basic information should also be documented not only to be valued by engineers and other processors, but also food scientists, plant breeders or growers, as well as other scientists who may exploit the potentials of these properties in developing new products for consumers (Mohsenin, 1970).

Several varieties of pomegranate fruits cultivated across the globe have gained a worldwide attention (Opara *et al.,* 2009; Hellen *et al.,* 2014). Pomegranate is a rich source of unique phytochemicals with various health benefits, with no toxicity associated with consumption of the fruit co-products (Wang *et al*., 2010). However, postharvest losses of pomegranate present a serious challenge to the South African pomegranate industry (Fawole & Opara, 2015). In industrial setting, postharvest losses occur when cutting pomegranate fruit and extracting and juicing the arils. Also, the disposal of pomegranate marc generated during juicing constitutes environmental issues (Fawole & Opara, 2015). There is therefore a need to make every pomegranate harvest count and utilise fruit waste generated during procession. This can only be achieved by investigating the quality attributes and functional properties of the fruit and co-products, and developing novel ways of utilizing the fruit waste (marc).

This review presents an overview of information on the quality attributes and functional properties of pomegranate relevant to processing and nutrition. Information on novel ways to utilise pomegranate fruit marc is also presented. Furthermore, preharvest and postharvest factors influencing these quality attributes and functional properties of pomegranate is discussed.

2. Pomegranate fruit

Pomegranate fruit is spherical and bears a distinctive, prominent tubular calyx at its crown. The fruit is made up of the edible and the non-edible fractions. The non-edible part (all fruit parts without arils) is often regarded as waste whereas the edible portion (arils), which constitutes 48 – 52% of the whole fruit, comprises 78% juice and 22% kernels (Dhumal *et al.*, 2014). An anatomy of the fruit reveals two distinct parts; the pericarp and the mesocarp. The pericarp is a smooth, tough, leathery skin, which is brownish-yellow to red when ripe. The mesocarp, also known as albedo, is made of a spongy tissue divided by a pulp membrane and vertical septal or placental membranes, also made of papery tissue (Morton, 1987). The pulp membrane further compartmentalizes the chambers of the mesocarp into groups of arils. These arils are transparent and a single aril contains flavourful juice and a kernel (Morton, 1987; Al-Maiman & Ahmad, 2002). The pomegranate kernel has a testa and tegmen. The tegmen bears an embryo while the testa is the fleshy, outer coat of the kernel (Morton, 1987). The pomegranate kernel also contains appreciable amounts of fibre, oil, nutrient, and mineral elements (Teixeira *et al.*, 2013; Hassan *et al.*, 2014). An illustration of a pomegranate fruit with its co-products is presented in Fig. 1.

2.1. Pomegranate fruit co-products

2.1.1. Peel

Depending on the cultivar, proportions of pomegranate peel range between 26% and 67% of the total fruit weight (Lansky & Newman, 2007; Ismail *et al.*, 2012; Sreekumar *et al.*, 2014). Pomegranate peel is an important source of bioactive polyphenols, organic acids, complex carbohydrates and minerals (Gil *et al.*, 2000; Vidal *et al.*, 2003; Van Elswijk *et al.*, 2004; Aslam *et al.*, 2006; Sreekumar *et al.*, 2014). A microscopic examination of pomegranate peel revealed a cuticle layer lying on top of the pericarp (Yazici *et al*., 2011). Beneath the epidermal cells is an organized layer of cuticle. Lenticels, observed to be mostly in lens shape, are also evenly distributed on the epidermis to facilitate gaseous exchange and to some extent, exchange of water vapour. Iso-diametrically shaped parenchyma cells are dispersed underneath the epidermal cells. In addition, parenchyma cells lie between vascular bundles and densely distributed sclerenchyma cells, which functioned by providing mechanical resistance against stretching and tearing in pomegranate fruit peel (Yazici *et al*., 2011).

According to Nasr *et al.* (1996), pomegranate peel is used in the preparation of food ingredients, tinctures and cosmeceutical. In Chinese medicine, it is used in treating diarrhoea, metrorrhagia, metrostaxis and bellyache (Wang *et al.*, 2010). The methanol peel extract demonstrated broad spectrum antioxidant activities (Singh *et al.*, 2002; Rahimi *et al*., 2012; Fawole *et al*., 2012). It also protected against CCl_4 toxicity and promoted the activities of hepatic enzymes in *in vivo* models (Murthy *et al*., 2002). Also, aqueous extract of the peel has been reported to effectively inhibits gastrointestinal transit, castor oil-induced diarrhoea enteropooling, natural movement of rat’s isolated ileum and weak acetylcholine-induced contractions with a strong anti-mutagenic property (Negi *et al*., 2003; Qnais *et al*., 2007). Furthermore, the peel extract in comparison to butylated hydroxytoluene stabilized sunflower oil and improved its resistance against heat and oxidative rancidity (Iqbal *et al*., 2008).

Also, both liquid and powder extracts of pomegranate peel showed anti-atherosclerotic property by reducing oxidative stress in mice macrophages (Aviram *et al*., 2008). Ismail *et al*. (2012) reported that the peel and its extract have gained acceptance for their wound healing and skin and breast cancer treatment therapies. In addition, the Egyptian culture has a record of using pomegranate peel extract in treating inflammation, diarrhoea, intestinal worms, cough and infertility (Ismail *et al*., 2012). In summary, although pomegranate peel remains of less interest to producers and processors, researches have shown that the peel and its extract possess an array of biological activities including antioxidant, cardiovascular, antimicrobial, tyrosinase enzyme inhibition and anti-inflammatory effects (Ismail *et al*., 2012; Fawole *et al*., 2012).

2.1.2. Aril and juice

Pomegranate aril refers to the edible, translucent, fleshy membrane that surrounds the kernel (Opara *et al*., 2015). The aril comprises 85% water, 10% sugars, and 1.5% pectin, organic acids and bioactive polyphenols of which anthocyanins constitute larger amount (Roy & Waskar, 1997; Viuda-Martos *et al*, 2010a). The pomegranate aril contains 76 – 85% juice, which accounts for approximately 30% of the fruit weight (Poyrazoglu *et al*., 2002; Lansky & Newman, 2007). Pomegranate arils are made of 7% proteins, 2.5% ash, 0.2% fat, 10% moisture and 79%

carbohydrates, of which dietary fibre and sugar constitute 11% and 57%, respectively (Aviram *et al.*, 2008). The aril sac, ranging from deep red to virtually colourless, microscopically comprises epidermal cells (Teixeira *et al.*, 2013). According to Aviram *et al.* (2008), pomegranate aril contains up to 70.5% hydrolysable tannins, 25% anthocyanins and approximately 5% ellagic acid derivatives.

Pomegranate aril extract has been demonstrated in both *in vitro* and *in vivo* models to decrease pro-oxidants activities and macrophage oxidative stress (Aviram *et al.*, 2008). Schubert *et al.* (1999) concluded that fermented pomegranate juice has a stronger antioxidant potential comparable to butylated hydroxyanisole and green tea (*Thea sinensis*), and is significantly higher than that of red wine (*Vitis vitifera*). An *in vivo* study showed that consumption of pomegranate juice for two weeks could appreciably reduce blood pressure and also substantially reduce the activity of angiotensin converting enzyme (Kowala *et al.*, 1994). In addition, a significant improvement of myocardial perfusion in 45 patients with ischemic cardiovascular disease was reported following consumption of PJ for 3 months (Sumner *et al.*, 2005).

2.1.3. Kernel and oil

Pomegranate kernels constitute up to 3% of the fruit weight and contain 12 – 20% oil (Lansky & Newman 2007; Khoddami *et al.*, 2014). According to Wang *et al.* (2004), pomegranate kernels contain proteins, pectin, sugars and complex polysaccharides (Dalimov *et al.*, 2003). Furthermore, two new compounds namely; coniferyl and sinapyl glycoside derivatives, isolated from the kernel are reported to inhibit conjugated dienes and malondialdehyde formation in a dose-dependent manner in rat brain. Also, ellagic acid and derivatives found in the kernel scavenged free radicals (Wang *et al.*, 2004; Seeram *et al.*, 2006). The kernels have been reported to improve beauty and combat infertility (Seeram *et al.*, 2006; Ajmal *et al.*, 2014). In a study by Das *et al.* (1999), the methanolic extract of the kernels effectively inhibited castrol-oil induced diarrhoea, along with prostaglandin E2-induced enteropooling and gastro-intestinal motility in rat. Moreover, the kernel testa contains derivatives of anthocyanin glucosides, and its matrix is embedded with 21.44% lignin and 18.71% cellulose (Dalimov *et al.*, 2003; Elfalleh *et al.*, 2012). According to Teixeira *et al.* (2013) and Sarikhani *et al.*, (2014), the abundance and distribution of sclerenchyma tissues present in the kernel testa determines its palatability and hardness, and the degree in hardness in tend drives decisions of choice made by consumers.

The kernel oil is a rich source of unsaturated fatty acids with a high content of punicic acid (65 – 85%) (Fadavi *et al.*, 2006; Jing *et al.*, 2012; Viladomiu *et al.*, 2013). Over 95% of pomegranate kernel oil is made of fatty acids containing 88 – 99% triacylglycerol (Tsuyuki *et al.*, 1981; Aslam *et al.*, 2006). In addition, tocopherols, sterols and cerebrosides have also been identified in appreciable amount in the kernel oil (Jing *et al.*, 2012; Fernandes *et al.*, 2015). Boussetta *et al.* (2009) demonstrated that punicic acid could exhibit anti-inflammatory property by limiting the activation of neutrophil and lipid peroxidation. This buttress the notion that pomegranate kernel is also a vital source of important bioactive pharmaceutical and nutraceutical phytochemicals (Khoddami *et al.*, 2014). The kernel oil has been reported to contain phenolic compounds implicated in antioxidant activities (Schubert *et al.*, 1999; Khoddami *et al.*, 2014; Siano *et al.*, 2015). According to Schubert *et al.* (1999), antioxidant capacity of cold-pressed pomegranate kernel oil is superior to that of red wine (*Vitis vitifera*) but as good as that of butylated hydroxyanisole and green tea (*Thea sinensis*). Other reported bioactivities of the kernel oil include suppressing tumour cell proliferations (Kim *et al.*, 2002; Lansky *et al.*, 2005), counteracting skin carcinogenesis (Hora *et al.*, 2003) and mammary carcinogenesis in mice (Mehta & Lansky, 2004), limiting accumulation of triglyceride in rat liver (Arao *et al.*, 2004), revitalising immune responses *in vivo* (Yamasaki *et al.*, 2006), and acting as a chemo-preventive factor through dietary formulation against cancers (Caligiani *et al.*, 2010).

3. Commercial importance of pomegranate

3.1. Production and Trade

The health benefit associated with the consumption of pomegranate fruit has led to its increasing demand (Seeram *et al.*, 2006). The fruit is ranked 18th in the world and projected to move to 10th place on the list within the next 10 years and this is majorly due to the improvement in cultivar selections, the bioavailable nutrients and phytochemicals present in the fruit, and the easy accessibility of the fruit arils in conveniently pre-packaged form (Citrogold, 2011; POMASA, 2012).

According to Citrogold (2011), the Northern Hemisphere supplies over 80% of the world's pomegranates. The world leaders in the production of pomegranate fruit in Northern Hemisphere include India (1,200,000 tons) followed by Iran (650,000 tons), United States of America (100,000 tons), Turkey (75,000 tons), Spain (60,000 tons), and Israel (20,000 tons) (Citrogold, 2011). However, in Southern Hemisphere, Chile, Argentina, Australia and South Africa are the leading producers of pomegranates (Brodie, 2009). Globally, India is known to have the largest area of pomegranate culture and production (Jadhav & Sharma, 2007) while the biggest exporter is Iran (Holland & Bar-Ya'akov, 2008). However, in terms of fruit yield per tree, Spain is ranked first followed by United States of America (Teixeira *et al.*, 2013).

The pomegranate industry in South Africa is growing rapidly and more attention is placed on improving compliance to export market demands. The total area of farmland was expanded from

754 to 785 ha in 2012 and 2014, respectively (Kotzé, 2012; Hortgro, 2014). Currently, the European Union (EU) is the biggest market destination of South African pomegranate, with 61% of total production exported in 2011. Other markets include Russia (12%), United Kingdom (11%), Middle East (9%), as well as Asia, Far East and Africa (7%) (Hortgro, 2014). Aside fruit export, local market in South Africa is growing fast. Consumption of fruit locally rose from 108 tons in 2011 to 302 tons in 2014 (Hortgro, 2014). As a result, it is predicted that South African pomegranate production and export will rise to 189% by 2017 (Kotzé, 2012; POMASA, 2012; Hortgro, 2014).

3.2. Industrial applications

3.2.1. Food and beverage industry

Due to the extraordinary health benefits of pomegranate, the food and beverage industry has experienced great growth and thus, continue to find a wider use for the fruit. Over the past years, the surge in the use of pomegranate as ingredients in functional foods and botanical dietary supplements has been greatly explored (Seeram *et al.,* 2006). At present, considerable attention is given to functional foods, which provide physiological benefits in fighting infections and retarding the progress of chronic diseases (Viuda-Martos *et al.,* 2010b).

Pomegranate fruit is used extensively in food and beverage industries for fortification and formulation of food products including yogurt, beverages and cereal bars (Casell, 2012). Nutritional attributes of the fruit such as low calories, high contents of fibre, polyphenols, organic acids, proteins, sugars, minerals, vitamins and oil are desirable in food and beverage industries (Fawole *et al.,* 2012; O'Grady *et al.,* 2014; Mphahlele *et al.,* 2015). As one of the most favourite table fruits, dried pomegranate arils give a sensational mouth feel and are therefore used as dessert (Mir *et al.,* 2012). The Northern Indians sun-dry the arils for 10-15 days and then sell as spice ('anardana'). Also in India, the fresh arils are used to prepare grenadine, which is used in marinating meat and mixing beverages (Morton, 1987; Da Silva *et al.,* 2013). Chefs use the fruit in salad dressing, food seasoning and in the preparation of other food products (Viuda-Martos *et al.,* 2010a; Casell, 2012). In addition, the fruit is used in the commercial production of jam, jelly, sauce, candy, syrup, beverage, baked food, colourant and flavoured cake (Seeram *et al.,* 2006; Ergun & Ergun, 2009; Mir *et al.,* 2012). In peninsular India, a unique wine, superior to grape vine, is prepared using pomegranate juice (Mir *et al.,* 2012).

3.2.2. Pharmaceutical industry

Being an ancient fruit, almost all parts of pomegranate is useful in pharmaceutics (Wang *et al.,* 2010). The fruit is called "super fruit" because of its potent healing ability (Da Silva *et al.,* 2013). The predominant effect of the whole fruit extract including pith, peel and kernels in decreasing considerably a marker associated with ageing effects as well as brain, muscle, liver and kidney impairment has led to claims of the fruit being “nature’s elixir of youth” (Cohen, 2011). As a result, the fruit is widely exploited in therapeutic formulations and cosmetics (Viuda-Martos *et al.*, 2010a).

Antioxidant polyphenols in pomegranate fruit co-products scavenge free radicals (Aviram *et al.*, 2008; Ismail *et al.*, 2012; Fawole *et al.*, 2013). Studies on cancer cell lines and animal models have evaluated the potency of the fruit extracts as anti-proliferative, anti-invasive and pro-apoptotic agents (Afaq *et al.*, 2005; Lansky *et al.*, 2005; Lansky & Newman, 2007). The anti-diabetic activity of pomegranate (Huang *et al.*, 2005; Katz *et al.*, 2007) and its ability to enhance cardiovascular health have also been explored (Aviram *et al.*, 2000; Basu & Penugonda, 2009; Davidson *et al.*, 2009). Furthermore, the fruit extract substantially inhibited nitric oxide production in *in vitro* models (Lee *et al.*, 2010). According to Mir *et al.* (2012), pomegranate juice is used in combination with drugs in treating dyspepsia. Also, the fruit cultivars with sweet taste tend to be mildly laxative, whereas sour-sweet and sour pomegranate fruits have an anti-inflammatory effect in stomach and heart organs (Mir *et al.*, 2012).

In oral health, mouth-rinsing with pomegranate extract reduced microbial population of dental plague, lowered saliva activities of aspartate aminotransferase and α-glucosidase, and further increased ceruloplasmin actions (Bielli & Calabrese, 2002; Nomura *et al.*, 2006; Menezes *et al.*, 2006). Pomegranate extract have also been demonstrated in inhibiting growth of many different types of bacterial species and strains (Reddy *et al.*, 2007; Al-Zoreky, 2009; Viuda-Martos *et al.*, 2010a). In addition, the extract inhibited the growth of HIV-1 and human influenza A/Hong Kong (H3N2) in *in vitro* models (Neurath *et al.*, 2005; Song *et al.*, 2005), curtailed replication of viral RNA (Haidari *et al.*, 2009) and synergistically enhanced the activities of antibiotics (Braga *et al.*, 2005).

Furthermore, Türk *et al.* (2008) claimed consumption of pomegranate juice increased epididymal sperm concentration, sperm motility, and spermatogenic cell density alongside increasing the diameter and thickness of seminiferous tubules and germinal cell layer respectively. In addition, erectile dysfunction was treated using the fruit extract (Forest *et al.*, 2007). This ultimately improved sperm quality, sex life and relief of stress (Cohen, 2011). Pomegranate derived products have been implicated in alleviation of allergies (Watanabe & Hatakoshi, 2002), as substitutes for hormone therapy (Lansky, 2000) and in treating HIV/AIDS (Lee & Watson, 1998).

3.2.3. Cosmeceutical industry

Cosmeceutical is a class of cosmetic products claimed to have medicinal properties (Chanchal & Swarnlata, 2008). Skin deterioration is a significant cause of morbidity and being a vital source of bioactive polyphenols, the fruit is used to stain the lip and cheeks (Aslam *et al.*, 2006; Kostick *et al.*, 2006). Recently, attention is given to pomegranate oil due to the presence of punicic acid unique to the oil (Khoddami *et al.*, 2014). Although publications on the use of pomegranate in this field is scanty, development of pomegranate-incorporated cosmetic products in enhancing skin beauty and health is greatly on the increase (Kostick *et al.*, 2007).

Pomegranate has been implicated in various skin repair and are reported to soften wrinkles, reduce skin aging and gently remove make-up thus, leaving skin soft, firm, silky, hydrated and bright. These agents also help to prevent hyperpigmentation and age spots, relieve sunburn and combat acne, breakouts, scars and sooth minor irritations (Anon., 2012; Summers, 2015). Pomegranate oil was reported to stimulate human keratinocyte proliferation. Also, aqueous extract of pomegranate fruit peel was found to activate dermal fibroblast proliferation and collagen synthesis while suppressing the major collagen-degrading enzyme in the skin (Aslam *et al.*, 2006). The combined bioactivity of pomegranate oil and the peel extract was reported to match that of biologically active retinoid, also known to reverse skin damage (Kligman *et al.*, 1986; Weiss *et al.*, 1988).

Commercially, available pomegranate-incorporated cosmeceuticals in South Africa include pomegranate facial toner, pomegranate softening facial wash, pomegranate firming serum, pomegranate firming day cream and lotion SPFI5, pomegranate softening cream cleanser, and pomegranate firming and refreshing eye roll-on. Also, several different varieties of 100% fruit pigmented pomegranate oil anti-aging lipsticks, with no synthetic dyes and preservatives, as well as pomegranate liquid soap and vitality shower are available on sales (Guojian, 1995; Anon., 2012).

3.2.4. Dye industry

The use of pomegranate for dyeing textiles can be traced from ancient times. In antique times in Mithila, currently located in Bihar, India, pomegranate fruit and leaf extracts were used in the production of dye and ink, respectively (Teixeira *et al.*, 2013). Yellow colourant derived from dried pomegranate fruit rind can be used as mordant and for dyeing clothes and hair (Dastur, 1964). Bruni *et al.* (2011) described the extraction and characterization of yellow colourant from commercially purchased dried pomegranate rind. Also, Kulkarni *et al.* (2011) recounted the dyeing of cotton textiles with colourant extracted from pomegranate fruit peels. Similarly, Anon. (2013) validated the techniques that are useful in dying clothes using pomegranate whole fruit.

4. Fruit properties

4.1. Physical properties

The physical properties of fruit are useful in designing equipment optimal for harvesting, transporting, grading, cleaning, storing and packaging, as well as processing whole fruit into other derived products. Therefore, designing processing tools and equipment without taking into consideration the physical properties of fruit could result in inefficient application and significant fruit quality losses. The knowledge of fruit physical properties is also vital in selecting fruit desirable for end-users (Stroshine, 1998; Sirisomboon *et al.*, 2007; Athmaselvi *et al.*, 2014).

In processing, the lineal dimensions and derivatives of fruit aid in evaluating the size of aperture and shape of equipment. These parameters help in estimating spacing of slicing discs, average number of fruit slices and fruit numbers that can be engaged per unit time (Naderiboldaji *et al.*, 2008). By comparison, pomegranate fruit harvested in several parts of the world are similar in length and diameter (Table 1). Knowledge of the lineal dimensions and derivatives of pomegranate fruit also helps in the designing of machine accessories such as bucket elevator, belt and screw conveyor (Sirisomboon *et al.*, 2007). Another important fruit property is aspect ratio, which defines oblong shape of a fruit (Arshad *et al.*, 2014). Pomegranate fruit shape is therefore essential in positioning the fruit prior to industrial pre-set operations (Stroshine, 1998). In addition, the shape designates the behaviour of fruit on oscillating surfaces (Oyelade *et al.*, 2005; Jahromi *et al.*, 2008). As presented in Table 1, pomegranate fruit shape is similar among several cultivars despite the differences in growing locations.

The weight of pomegranate fruit forms an integral factor considered in designing packaging and modelling plant yield and load for transfer and storage (Arshad *et al.*, 2014). Bigger pomegranate fruit weight was recorded for cultivars grown in South Africa, Morocco, Tunisia and Croatia (Table 1). As an implication, bigger plant yield and load may be needed for transporting and storing pomegranate fruit grown in the abovementioned countries. The surface area and volume of pomegranate fruit are both imperative in modelling heat and mass transfer in cooling and drying processes, as well as in examining the fruit shape and respiration rate (Stroshine, 1998; Oyelade *et al.*, 2005; Jahromi *et al.*, 2008). Bigger volume and surface area of pomegranate fruit may therefore imply a slower heat and mass transfer accompanied by a higher respiration rate (Table 1).

Furthermore, the sphericity and radius of curvature of pomegranate fruit facilitates its rolling or sliding ability. Thus, a high sphericity value implies fruit roundedness hence fruit rolls whereas the opposite would indicate a sharp curvature resulting in sliding of the fruit (Stroshine, 1998; Omobuwajo *et al.*, 2000; Athmaselvi *et al.*, 2014). As presented in Table 1, the ranges reported for sphericity of pomegranate fruit from different countries were similar. Density is fundamental in establishing differences among fruits. Density is reliable in defining flow rate and energy demand for pumping, centrifugation and sedimentation separating techniques (Stroshine, 1998). True density (derived by water displacement), bulk density (derived by packing fruits in an empty container) and porosity are vital when grading and transporting fruit by hydrodynamics (Aviara *et al.*, 2007; Sirisomboon *et al.*, 2007). True density is handy when investigating the equivalent sphere diameter of fruit while bulk density is imperative in designing fruit extractor and storage bins (Aviara *et al.*, 2007; Sirisomboon *et al.*, 2007). Although pomegranate fruits of different origin have similar density, as high as 1.23 g/cm^3 was reported for cultivars harvested in South Africa (Table 1).

There are other important fruit properties that have not yet been investigated for South African pomegranate fruit. For instance, in designing storage structures, the static coefficient of friction is needed in calculating fruit compressibility and flow behaviour (Athmaselvi *et al.*, 2014). Frictional properties of fruit are vital in designing handling equipment since they account for the level of resistance at which a fruit is held on a conveyer and the amount of power necessary to convey the fruit. This is therefore a prerequisite for selecting varying degree of smooth surfaces necessary for fruit discharge (Sirisomboon *et al.*, 2007; Jahromi *et al.*, 2008; Arshad *et al.*, 2014). The static coefficient of friction is also required in evaluating the maximum inclination angle of conveyors and storage bins (Sirisomboon *et al.*, 2007).

4.2. Sensory properties

The qualities that govern marketability of fruit include colour, texture, yield and flavour, and as an implication, a minor difference in any of these factors could have a substantial impact on the fruit acceptability (Fellows, 2009; Schulze *et al.*, 2015). Fruit stakeholders such as growers, processors and consumers may rely on these to assess fruit freshness and maturity (Arshad *et al.*, 2014). According to Table 1, there were no big differences in aril yield of pomegranate cultivars grown in different locations. Nonetheless, these findings could inform cultivar selection especially for juice processing where pomegranate cultivars having higher edible fruit part (arils) are more desirable. Although fruit colour hardly, positively correlate with fruit quality, it does play a role in differentiating among cultivars (Opara *et al.*, 2009; Mditshwa *et al.*, 2013; Fawole & Opara, 2013e). For instance, peel lightness of pomegranate fruit of Oman and Israel origin was higher than peel lightness of South African pomegranate fruit. However, peel redness of South African pomegranate fruit was higher than those of Oman and Israel (Table 2). A similar trend was also observed in arils colour for South African and Omani pomegranate fruit (data not shown) (Al-Said *et al.*, 2009; Fawole & Opara, 2013b). As mostly characterised by redness, consumers would be more attracted to purchase pomegranate grown in South Africa primarily because of its higher redness attribute.

4.3. Textural properties

The response of fruit to applied loads and bruises is inevitable (Linares & Castillo, 2013). Mechanical harvesting, bulk handling, transporting and storage of fruit indicate an important need for knowledge of the fruit textural properties (Mohsenin, 1970). In addition, this knowledge will aid to optimize processes, design equipment for harvesting and handling, and reduce fruit quality losses (Singh & Reddy, 2006; Ekrami-Rad *et al.*, 2011). Secondly, fruit abilities in resisting physiological or pathology changes during maturation, ripening or storage can be understood using the knowledge of their textural properties (Rao & Steffe, 1992). Furthermore, extracting the edible part of specifically, pomegranate fruit would require information on their cutting susceptibility, puncture resistance, toughness, firmness, rupture force and shear strength (Mansouri *et al.*, 2011; Ekrami-Rad *et al.*, 2011). From an energy stand-point, knowledge of the textural properties of pomegranate can be used to determine the most suitable technique to breakup or crush the fruit or fruit co-products (arils and kernels) (Mohsenin, 1970).

Knowledge of the force and energy required to cut pomegranate fruit is vital in designing and constructing cutting units (Ekrami-Rad *et al.*, 2011). Fruit resistance to puncture, as related to its hardness or firmness, can be explored in optimising handling processes and equipment. More so, the puncture resistance and elastic modulus are both applicable in predicting fruit firmness or hardness (Singh & Reddy, 2006; Arendse *et al.*, 2014c). In defining the interfacial toughness of fruit, compression test is carried out (Thouless & Yang, 2008). As a result, the distortion of fruit at its rupture point facilitates the sizing of gaps between equipment surfaces involved in compressing and dehulling fruit (Sirisomboon *et al.*, 2007).

Also, the firmness of pomegranate fruit and aril co-product inform on their susceptible to bruise damage (García *et al.*, 1995). Firmer pomegranate fruit and arils are reported to have low membrane lipid catabolism and stable shelf life (Herbert *et al.*, 1999; Cavalcante *et al.*, 2012). Firmness is therefore used to follow up the cell wall integrity, turgor pressure and maturity evolution of pomegranate fruit and aril co-product (Sousa *et al.*, 2003; Ekrami-Rad *et al.*, 2011). According to the research data presented in Table 3, the firmness and toughness of South African pomegranate arils were distinctly greater. As a result, a higher force may be required to crush South African pomegranate arils to generate juice.

Furthermore, textural properties such as hardness and compressive resistance of pomegranate kernels constitute important engineering parameters in studying and understanding the kernels' resistance to grinding (Mohsenin, 1970). Hardness of pomegranate kernels has been a subject of interest to the pomegranate industry, consumers and livestock feeders. Similar to the arils, the hardness and toughness of pomegranate kernels were higher for fruit cultivars obtained in

South Africa than those from Oman (Table 3). From processing viewpoint, this information can be used by processors to determine the best technique to crush pomegranate kernels for oil extraction. On the contrary, harder pomegranate kernels may stipulate larger content of dietary fibre, hence the need to explore them in high fibre food formulations. Overall, the arils and kernels extracted from pomegranate grown in Oman would require lower mechanical energy for compression and therefore would be easier to process than those of South African origin.

4.4. Physico-chemical properties

4.4.1. Maturity index and pH

According to Herbert *et al.* (1999), total soluble solids (TSS) and titratable acidity (TA) of a fruit give indications of whether it can be consumed prior or after processing. For instance, a high TSS and a low TA of a fruit means it can be consumed whilst fresh. Moreover, the ratio of TSS to TA of a fruit defines its maturity index (MI) (Fawole & Opara, 2013a). An optimised MI reflects on a fruit quality and therefore serves to reveal optimum periods for harvesting fruits in meeting quality standards (Fawole & Opara, 2013c; Fawole & Opara, 2013d). In marketing, MI determines sales of varying degree of matured fruits (Reid, 2002). Another important property, pH plays an important role in characterizing fruit sourness. The pH of fruit is also used to set time and temperature for pasteurization. Thus, the lower the fruit pH, the shorter the time and the lower the temperature required for its pasteurization (Fellows, 2009).

4.4.2. Organic acids and sugars

The presence of organic acids and sugars in fruit determine its degree of sourness or sweetness, stability and storability (Shui & Leong, 2002; Hellen *et al.*, 2014). Organic acids and sugars have been reported to be higher in pomegranate fruit grown in Turkey than South Africa (Ozgen *et al.*, 2008; Fawole *et al.*, 2013; Mditshwa *et al.*, 2013; Mphahlele *et al.*, 2015; O’Grady *et al.*, 2014; Arendse *et al.*, 2014c). This has a great impact on the sourness or sweetness perceptibility of pomegranate from the two abovementioned countries. In addition, some organic acids and sugars have been implicated to exhibit synergistic and antagonistic effect in enhancing sweetness of pomegranate fruit. For instance, malic acid is reported to promote sucrose perceptibility whereas citric acid masks sucrose and fructose expression (Athmaselvi *et al.*, 2014). Also, some organic acids, like ascorbic acid neutralizes free radicals, improves mineral absorption and renal health, and minimizes the risk of cardiovascular diseases and carcinogens (Hellen *et al.*, 2014; Kukreti, 2015). In addition, knowledge of the composition of organic acids of a fruit can be used to follow up fruit developmental stages to optimise harvesting time (Hellen *et al.*, 2014).

4.4.3. Polyphenols and antioxidant

Polyphenols are important phytochemicals established to be nontoxic with nutritional and therapeutic bioactivities (Pérez-Vicente *et al.*, 2002). These include combating against cancer, inflammation, cardiovascular and neurodegenerative ailments, as well as other chronic diseases by partly scavenging free radicals implicated in impairing proteins and nucleic acids (Murthy *et al.*, 2002; Vattem & Shetty, 2005; Seeram *et al.*, 2006). Several studies have concluded that pomegranate fruit is a rich source of important polyphenols and therefore possess potent antioxidant capacity (Mousavinejad *et al.*, 2009; Fawole *et al.*, 2012; Arendse *et al.*, 2014b; Li *et al.*, 2015). The polyphenolic composition of pomegranate fruit may be the reason why the fruit is multifunctional in treating a vast degree of ailments and other chronic diseases (Lee & Watson, 1998; Watanabe & Hatakoshi, 2002; Al-Zoreky, 2009; Davidson *et al.*, 2009).

4.4.4. Proximate and mineral content

Nutrient imbalances exacerbate disorders (Crisosto & Costa, 2008). The nutritional composition of fruit may allow nutritionists and consumers to use them as dietary supplement or as an alternate source of food (Machado *et al.*, (2015). O'Grady *et al.* (2014) reported on the proximate composition of South African pomegranate arils to be moisture (0.79 – 0.80 g/g), ash (5.20 – 5.40 g/kg), fat (13.0 – 15.0 g/kg), dietary fibre (26.0 – 29.0 g/kg), protein (11.0 – 12.0 g/kg), carbohydrate (141.0 – 150.0 g/kg) and total energy (314.0 – 319.0 kJ/100 g). Aside that, several dietary minerals were also reported to be present in appreciable amounts in South African pomegranate arils (Fawole & Opara, 2012; Fawole & Opara, 2013a). Whilst such data on South African pomegranate kernels is unavailable at the time of this review, other studies on pomegranate kernels derived from cultivars in Nigeria, Egypt, Italy, Iran, Pakistan and Saudi Arabia have demonstrated the kernels to be a good source of bioactive oil and minerals (El-Nemr *et al.*, 1990; Al-Maiman & Ahmad, 2002; Dangoggo *et al.*, 2012; Khoddami *et al.*, 2014; Siano *et al.*, 2015).

4.4.5. Kernel oil indices

Free fatty acids (FFA), iodine value (IV), peroxide value (PV), *para*-anisidine value (*p*-AV) and saponification number (SN) are important indices that define the present condition of oil (Khoddami *et al.*, 2014). IV is a measure of the degree of unsaturation in oil and therefore indicates the susceptibility of oil to oxidation. Low IV is therefore associated with a lower degree of unsaturation and a higher resistance of oil to oxidation (Moodley *et al.*, 2007; Machado *et al.*, 2015). Lipolysis and rancidity in oil is directly proportional to its FFA index (Choo *et al.*, 2007). To tell on the onset of oxidation in oil, conjugated dienes (CD), conjugated trienes (CT), PV and *p*-AV are used. CD and PV are both used to quantify primary oxidation molecules (dienes and peroxides) whereas CT and *p*-AV are used to measure secondary oxidation products (trienes and carbonyls) in oil (Chander, 2010; Anon., 2015a). Knowledge of SN of oil can be used to predict the length of fatty acids in the oil. Low SN therefore is an indication of long chain fatty acids (Anon., 2015b).

Refractive index (RI) is an intrinsic property of oil measured based on light penetration through an oil sample (Aydeniz *et al*., 2014; Khoddami *et al*., 2014). Oil RI is directly proportional to its degree of unsaturation and inversely related to its viscosity and is therefore used to quantify the double bonds of fatty acids (Aydeniz *et al*., 2014; Khoddami *et al*., 2014). An oil's specific gravity defines its quality (Pedranti, 2009). The index of atherogenicity (IA) and thrombogenicity (IT) shows the extent of physiological health implications of oil. IA compares saturated fatty acids, specifically myristic, palmitic and stearic acids, since they facilitate the bonding of lipids to cells of the immunological and circulatory system, to all forms of monounsaturated and polyunsaturated fatty acids, specifically omega-3 and omega-6 fatty acids. Equally, IT serves the purpose of analysing the tendency of oil to form clot in blood vessels (Ulbritch & Southgate, 1991; Senso *et al*., 2007; Garaffo *et al*., 2011).

6. Factors affecting fruit properties

6.1. Preharvest factors

6.1.1. Genetic and cultivar differences

The differences among pomegranate cultivars are predominantly brought about by their variant genetic composition. For instance, cv. Wonderful fruit was described as the hardest among seven South African pomegranate varieties (Fawole & Opara, 2013e). However, pomegranate cultivars grown in Oman were softer than any of the pomegranate fruit harvested in South Africa (Al-Said *et al*., 2009). Also, analysis of pomegranate kernel oil extracted from fruit cultivars grown in different parts of the world shows major differences in their oil indices, chemical properties and degree of unsaturation among the cultivars (Melgarejo *et al*., 1995; Hernández *et al*., 2000; Hernández *et al*., 2011; Fadavi *et al*., 2006; Parashar, 2010; Moayedi *et al*., 2011. Akbari *et al*., 2014; Khoddami *et al*., 2014; Verardo *et al*., 2014; Siano *et al*., 2015). All these variations can be due to the cultivars' genetic compositions.

6.1.2. Location and climate

Differences in geographical locations and climatic conditions have significantly imparted discrepancies to fruit properties. Tables 1 - 3 present the differences in properties among the various selected geographies. Studies conducted by Mditshwa *et al.* (2013) and Mphahlele *et al.* (2015) using cv. Bhagwa and Wonderful, respectively, demonstrate how differences in altitude, rainfall, light intensity and relative humidity partly impart on fruit properties. According to Mditshwa *et al.* (2013) cv. Bhagwa grown in Wellington (least attitude and highest temperature, light intensity, relative humidity and rainfall) had brightest colour intensity in fruit peel. This was in agreement with findings of Ubi (2004). Likewise, the reverse was also true as cv. Bhagwa cultivated in Wellington recorded the least fruit weight, diameter, compressibility resistance and moisture content. In addition, similar trends in relation to other fruit properties in cv. Wonderful were reported by Mphahlele *et al.* (2015).

6.1.3. Irrigation and fertilizers

Irrigation and fertilizer application rates vary extensively as they are driven by soil type, outcome of field testing, temperature, humidity, landscape of farmland and history of cropping (Crisosto & Costa, 2008). A 5 year duration study on impart of biofertilizers application on pomegranate trees grown on a loamy, sandy farm soil (pH 8.1, field capacity 150 mm m^{-1}) located at 26°18′N and 73°01′E (Thar Desert, India) with temperatures ranging between 25 – 35°C and watered on alternate days to field capacity showed that biofertilizers improved pomegranate fruit yield and increased the fruit sugars, phenolics, minerals and amino nitrogen concentrations (Aseri *et al.*, 2008).

Also, moderate (43%) and severe (12%) sustained deficit irrigation of cv. Molla de Elche trees grown in a silt, loamy farm soil (saline (5.9 dS m^{-1}), calcium carbonate (200 g kg^{-1}), low potassium and high phosphorus content) near Murcia, Spain led to the production of pomegranate juice characterised by yellowish colour, low content of total phenolic, total anthocyanins and punicalagin contents, as well as poor antioxidant capacity (Mena *et al.*, 2013). Similarly, poor yield, small sized-fruit, and a slow fruit growth characteristics were observed on moderately water stressed pomegranate plant (Mellisho *et al.*, 2012). Unlike deficit irrigation, well-watered pomegranate trees produced firmer fruits (García *et al.*, 1995).

6.1.4. Tree age, architecture and crop load

Age of trees, fruit orientation on trees and canopy defines tree characteristics. Age of trees influences efficiency of plants’ natural system. This therefore imparts gradual changes on yield, physico-textural and bioactivities of fruit (Arshad *et al.*, 2014). Although scanty information on tree characteristics exist for pomegranate, O'Neill (2015) established that pomegranate trees live for a minimum of 200 years and ultimately produce best quality fruits during its first 20 years. Even so, pomegranate trees take a minimum of 4 years to mature (O'Neill, 2015).

6.1.5. Fruit maturity

A well-defined harvest time is very crucial as maturity affects fruit quality (Crisosto & Costa, 2008). Although many indices have been employed, the ratio of total soluble solids to titratable acidity is the most used parameter to evaluate fruit maturity. In a particular study, the physical and chemical properties of South African cv. Ruby and Bhagwa cultivated across five different maturity and ripening stages in two successive seasons were distinct at each stage (Fawole & Opara, 2013a; Fawole & Opara, 2013f). This was consistent to the review of Crisosto & Costa (2008), who concluded that delaying fruit harvest time could improve fruit sensory characteristics whilst enhancing softening and subsequently, fruit spoilage.

6.2. Postharvest factors

6.2.1. Storage environment, atmosphere and duration

Different time-temperature combination regimes are used in enhancing storability of pomegranate fruit. However, these tend to modify the fruit properties (Artés *et al.*, 1998; Artés *et al.*, 2000a; Mirdehghan *et al.*, 2006; Mirdehghan *et al.*, 2007). According to O'Grady *et al.* (2014), pomegranate arils of Arakta, Bhagwa and Ruby fruit cultivars stored at 1°C, 4°C, and 8°C for 14 days with 95% relative humidity (RH) exhibited high respiration rate as temperature increased. This was consistent with the study of Elyatem & Kader (1984). The different time-temperature combinations also affected the anthocyanins, ascorbic acid and β-Carotene contents of the cultivars (O'Grady *et al.*, 2014). However, the proximate composition of the arils stored at 1°C and 4°C for 14 days was unaffected (O'Grady *et al.*, 2014). In another study, high total soluble solids, low titratable acidity, juice yield and low colour attributes and compressibility properties of cv. Wonderful stored at 5°C, 7.5°C, and 10°C for 4 months with 92% RH were reported (Arendse *et al.*, 2014a). Under same conditions, the ascorbic acid content and DPPH radical scavenging activity of cv. Wonderful decreased throughout the storage period (Arendse *et al.*, 2014b).

6.2.2. Packaging

6.2.2.1. Modified atmosphere packaging

Modified atmosphere packaging (MAP) is a passive or active way of changing the composition of gases inside a packaged food without further controls (Fellows, 2009; Caleb *et al.*, 2012). The use of MAP has aided processors in packaging pomegranate arils. However, MAP alters the properties of pomegranate arils (Caleb *et al.*, 2012; Caleb *et al.*, 2013; Hussein *et al.*, 2015). For instance, Banda *et al.* (2015) concluded that arils of 'Wonderful' packaged in polyethylene terephthalate clamshell trays modified with 5-30 kPa O_2, 10-40 kPa CO_2, and 30-85 kPa N_2, and stored at 5°C for 12 days had a low respiration rate and a high anthocyanin content. According to Artés *et al.* (2000b), MAP reduced moisture loss and chilling injuries with no trace of decay in arils of Spanish cv. Mollar de Elche kept under 25 µm thick unperforated polypropylene film that was only permeable to 1718 mL O_2/m^2 and 3668 mL CO_2/m^2 days modified atmospheres at 2°C.

6.2.2.2. Film packaging

Film packaging are important in preserving pomegranate fruit quality (Nanda *et al*., 2001; Ghafir *et al*., 2010; Abd-elghany *et al*., 2012). Pomegranate fruit (cv. Ganesh) shrink wrapped in polyolefin film (BDF-2001 and D-955) and stored at 8°C for 12 weeks had a reduced respiration rate and weight loss and a stable sugar and vitamin C content (Nanda *et al*., 2001). In another study, Abd-elghany *et al*. (2012), in two successive seasons, examined the effects of polyolefin film wrapper (BDF-2001) and varying concentrations of calcium chloride that were in 4 min contact with cv. Wonderful fruit and recounted that after air drying the fruit at 24°C and storing them at 5°C with 85% RH for 2 months could prevents excessive weight loss and respiration rate and retain fruit firmness, peel thickness, ascorbic acid concentration and organoleptic properties with enhanced shelf life.

6.2.3. Processing

6.2.3.1. Extraction method

Choosing an optimised extraction technique to juice pomegranate arils or extract oil from the kernels is essential in processing and nutrition (Sun *et al*., 2011). Among seven different extraction methods, pomegranate juice obtained by crushing whole fruit had a stronger antioxidant potential and a lower acidity, total soluble solids, proteins and phenolic contents (Rinaldi *et al.*, 2013). In agreement with Gil *et al.* (2000) and Rosenblat & Aviram (2006), the antioxidant effect of the juice was attributed to hydrolyzable tannins that leached from the fruit rind into the juice by pressing the whole fruit. However, the leached tannins made the juice bitter and unwholesome (Rinaldi *et al*., 2013).

Furthermore, with the aid of ultrasonic assisted extraction, pomegranate oil yield was in order of petroleum ether > hexane > ethyl acetate > diethyl ether > acetone > isopropanol. Much lower oil yield was reported when Soxhlet and supercritical CO_2 oil extraction techniques were used (Tian *et al.*, 2013). In another study, response surface supercritical CO_2 pomegranate oil contained 14% more total tocopherols than Soxhlet assisted *n*-hexane pomegranate oil (Liu *et al*., 2009). An increase in modifier pressure, temperature and volume in supercritical CO_2 extraction decreased the phenolic content of pomegranate oil (Liu *et al*., 2009).

6.2.3.2. Juice clarification

Clarification is vital to prevent juice cloudiness which is mainly due to the presence of pectin and polyphenols in the juice (Vardin & Fenercioğlu, 2003; Alper *et al*., 2005; Rinaldi *et al*., 2013). According to Rinaldi *et al.* (2013), pectolytic clarification of pomegranate juice led to an increase in soluble solids, organic acids, proteins and polyphenols contents. On the contrary, the breakdown of polyphenols, pigment, soluble solids and organic acids in gelatin, bentonite and polyvinyl polypyrrolidone (PVPP) clarified pomegranate juice was reported (Vardin & Fenercioğlu, 2003; Alper *et al*., 2005; Alper *et al*., 2011). In addition, the pH of gelatin and PVPP clarified pomegranate juice was observed to increase (Vardin & Fenercioğlu, 2003). However, no important change in organic acids and phenolic content were observed in ultrafiltered pomegranate juice (Alper *et al*., 2011).

Conclusions and future prospects

Pomegranate fruit cultivars harvested in different regions have distinct qualities. Nonetheless, all properties of pomegranate fruit are vital in processing and nutrition. The physical properties of pomegranate fruit are necessary engineering parameters that help processors to design equipment for harvesting, packaging, transporting and processing whole pomegranate fruit into other derived products. Knowledge of textural properties of pomegranate fruit is relevant in understanding fruit responses to cutting strength, compressibility and puncture forces. In addition, this knowledge will aid to optimize processes and design equipment for extracting the edible part of pomegranate fruit by determining the most suitable extraction technique. Therefore, designing processing tools and equipment without paying attention to the physical and mechanical demands of pomegranate fruit could result in inefficient processing application and fruit quality losses. On the other hand, the sensory properties of a matured and a quality pomegranate fruit can be used as a yardstick for the marketability of the fruit cultivar. Furthermore, knowledge of the chemical characteristics of pomegranate fruit is important in selecting fruit cultivars desirable for end-users. In view of this, investigations on the quality attributes and functional properties of pomegranate fruit and co-products relevant to processing and nutrition is needed.

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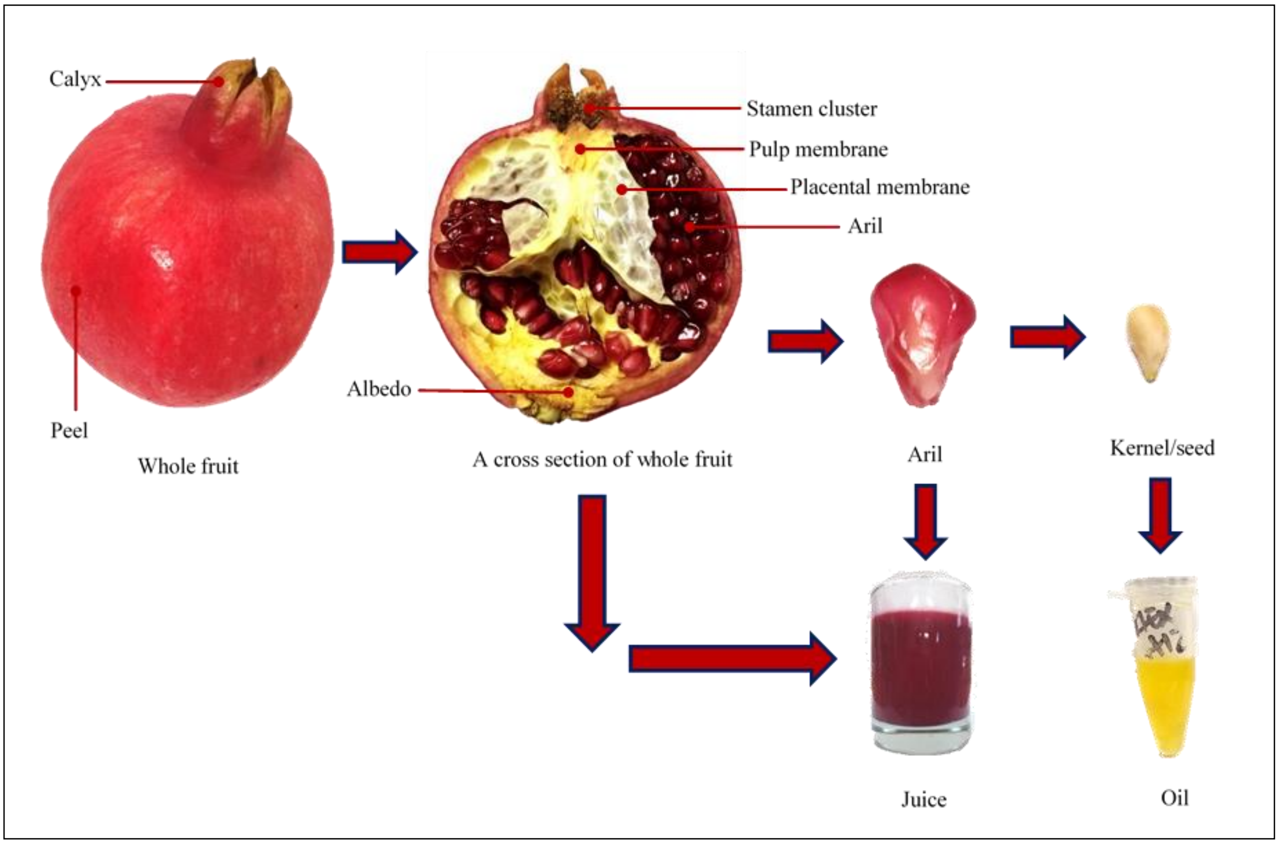

Fig. 1. Basic structure of a pomegranate fruit with its co-products

Table 1: Physical properties of whole fruit of pomegranate cultivars grown in different regions of the world

Property	South Africa (8 cultivars)	Oman (4 cultivars)	Morocco (10 cultivars)	Iran (3 cultivars)	Tunisia (13 cultivars)	Spain (6 cultivars)	Croatia (8 cultivars)	References
Length (mm)	68.7 – 88.7	66.2 – 83.6	58.9 – 89.2	71.6 – 88.1	51.5 – 88.8	74.0 – 82.4	59.4 – 91.5	Fawole & Opara, 2013e; Al-Said *et al*., 2009; Martínez *et al*., 2012; Hmid *et al*., 2016; Tarighi *et al*., 2011; Riyahi *et al*., 2011; Koshmann *et al*., 2007; Zaouuay *et al*., 2012; Hernández *et al*., 2014; Radunić *et al*., 2015.
Diameter (mm)	75.0 – 99.7	69.8 – 93.9	72.1 – 100.4	75.3 – 116.0	56.8 – 101.3	88.3 – 96.0	67.7 – 96.9	Fawole & Opara, 2013e; Al-Said *et al*., 2009; Martínez *et al*., 2012; Hmid *et al*., 2016; Tarighi *et al*., 2011; Riyahi *et al*., 2011; Koshmann *et al*., 2007; Zaouuay *et al*., 2012; Hernández *et al*., 2014; Radunić *et al*., 2015.
Shape index (length**:**diameter)	0.82 – 0.96	0.86 – 0.94	0.82 – 0.89	0.76 – 0.95	0.88 – 0.91	0.84 – 0.86	0.85 – 0.95	Fawole & Opara, 2013e; Al-Said *et al*., 2009; Martínez *et al*., 2012; Hmid *et al*., 2016; Tarighi *et al*., 2011; Riyahi *et al*., 2011; Koshmann *et al*., 2007; Zaouuay *et al*., 2012; Hernández *et al*., 2014; Radunić *et al*., 2015.
Weight (g)	274.0 – 509.8	187.1 – 424.3	206.6 – 535.1	245.5 – 331.6	101.3 – 549.7	333.5 – 464.2	189.4 – 595.9	Fawole & Opara, 2013e; Al-Said *et al*., 2009; Martínez *et al*., 2012; Hmid *et al*., 2016; Tarighi *et al*., 2011; Riyahi *et al*., 2011; Koshmann *et al*., 2007; Zaouuay *et al*., 2012; Hernández *et al*., 2014; Radunić *et al*., 2015.
Volume (cm^3)	222.5 – 506.1	178.0 – 432.1	196.1 – 529.6	244.0 – 326.5	95.9 – 544.0	360.3 – 463.0	204.0 – 601.0	Fawole & Opara, 2013e; Al-Said *et al*., 2009; Martínez *et al*., 2012; Hmid *et al*., 2016; Tarighi *et al*., 2011; Riyahi *et al*., 2011; Koshmann *et al*., 2007; Zaouuay *et al*., 2012; Hernández *et al*., 2014; Radunić *et al*., 2015.

Table 1 (continues)

Table 1: Physical properties of whole fruit of pomegranate cultivars grown in different regions of the world

Property	South Africa (8 cultivars)	Oman (4 cultivars)	Morocco (10 cultivars)	Iran (3 cultivars)	Tunisia (13 cultivars)	Spain (6 cultivars)	Croatia (8 cultivars)	References
Density (g/cm^3)	0.94 – 1.23	0.96 – 1.05	1.01 – 1.05	0.97 – 1.02	1.01 – 1.05	0.92 – 1.00	0.93 – 0.99	Fawole & Opara, 2013e; Al-Said *et al.*, 2009; Martínez *et al.*, 2012; Hmid *et al.*, 2016; Tarighi *et al.*, 2011; Riyahi *et al.*, 2011; Koshmann *et al.*, 2007; Zaouuay *et al.*, 2012; Hernández *et al.*, 2014; Radunić *et al.*, 2015.
Geometric mean diameter (mm)	72.5 – 84.6	68.6 – 90.3	67.4 – 96.5	74.0 – 105.8	54.9 – 96.9	83.2 – 91.2	64.8 – 95.0	Fawole & Opara, 2013e; Al-Said *et al.*, 2009; Martínez *et al.*, 2012; Hmid *et al.*, 2016; Tarighi *et al.*, 2011; Riyahi *et al.*, 2011; Koshmann *et al.*, 2007; Zaouuay *et al.*, 2012; Hernández *et al.*, 2014; Radunić *et al.*, 2015.
Sphericity	1.02 – 1.08	1.04 – 1.10	1.08 – 1.14	1.03 – 1.20	1.06 – 1.09	1.10 – 1.12	1.03 – 1.09	Fawole & Opara, 2013e; Al-Said *et al.*, 2009; Martínez *et al.*, 2012; Hmid *et al.*, 2016; Tarighi *et al.*, 2011; Riyahi *et al.*, 2011; Koshmann *et al.*, 2007; Zaouuay *et al.*, 2012; Hernández *et al.*, 2014; Radunić *et al.*, 2015.
Surface area (cm^2)	165.6 – 281.3	148.0 – 256.6	142.6 – 292.5	172.1 – 351.7	94.8 – 295.1	217.6 – 261.3	131.8 – 283.7	Fawole & Opara, 2013e; Al-Said *et al.*, 2009; Martínez *et al.*, 2012; Hmid *et al.*, 2016; Tarighi *et al.*, 2011; Riyahi *et al.*, 2011; Koshmann *et al.*, 2007; Zaouuay *et al.*, 2012; Hernández *et al.*, 2014; Radunić *et al.*, 2015.
Volume of oblate spheroid (cm^3)	202.2 – 461.4	168.8 – 385.8	160.2 – 470.6	212.5 – 620.4	87.0 – 474.9	301.9 – 397.4	142.5 – 449.6	Fawole & Opara, 2013e; Al-Said *et al.*, 2009; Martínez *et al.*, 2012; Hmid *et al.*, 2016; Tarighi *et al.*, 2011; Riyahi *et al.*, 2011; Koshmann *et al.*, 2007; Zaouuay *et al.*, 2012; Hernández *et al.*, 2014; Radunić *et al.*, 2015.
Aril yield (%)	47.5 – 68.1	54.5 – 66.8	53.4 – 69.4	–	37.8 – 61.7	52.6 – 65.8	35.7 – 62.1	Fawole & Opara, 2013e; Al-Said *et al.*, 2009; Martínez *et al.*, 2012; Hmid *et al.*, 2016; Zaouuay *et al.*, 2012; Hernández *et al.*, 2014; Radunić *et al.*, 2015.

Table 2: CIE peel colour attributes of pomegranate fruit cultivars grown in South Africa, Oman and Israel

	South Africa								Oman				Israel		
Attribute	Acco	Arak	Bhagwa	Gane	Hersk	MdeE	Ruby	Wond	Jab 1	Jab 2	Jab 3	Wild	Rosh-Hapered	Wonderful	Refeerence
Lightness (*L**)	46.7	35.8	41.1	41.1	34.2	54.2	27.5	44.9	-	-	-	-	-	-	Fawole & Opara, 2013e
	-	-	42.9 - 49.3	-	-	-	-	-	-	-	-	-	-	-	Mditshwa *et al.*, 2013
	-	-	-	-	-	-	44.2 - 46.5	-	-	-	-	-	-	-	Fawole & Opara, 2013a
	-	-	-	-	-	-	-	-	55.7	63.7	58.9	87.4	-	-	Al-Said *et al.*, 2009
	-	-	-	-	-	-	-	-	-	-	-	-	34.2 - 59.3	52.5 - 58.6	Shwartz *et al.*, 2009
Redness (*a**)	47.7	40.8	44.8	34.0	43.0	16.3	24.6	43.9	-	-	-	-	-	-	Fawole & Opara, 2013e
	-	-	39.2 - 43.2	-	-	-	-	-	-	-	-	-	-	-	Mditshwa *et al.*, 2013
	-	-	-	-	-	-	40.3 - 43.1	-	-	-	-	-	-	-	Fawole & Opara, 2013a
	-	-	-	-	-	-	-	-	35.6	10.2	21.6	15.2	-	-	Al-Said *et al.*, 2009
	-	-	-	-	-	-	-	-	-	-	-	-	35.2 - 37.3	34.4 - 39.4	Shwartz *et al.*, 2009
Yellowness (*b**)	25.8	13.8	18.5	16.8	17.2	24.0	6.7	22.6	-	-	-	-	-	-	Fawole & Opara, 2013e
	-	-	22.7 - 29.9	-	-	-	-	-	-	-	-	-	-	-	Mditshwa *et al.*, 2013
	-	-	-	-	-	-	21.9 - 30.2	-	-	-	-	-	-	-	Fawole & Opara, 2013a
	-	-	-	-	-	-	-	-	27.1	35.3	32.3	4.4	-	-	Al-Said *et al.*, 2009
	-	-	-	-	-	-	-	-	-	-	-	-	14.9 - 25.1	23.9 - 31.7	Shwartz *et al.*, 2009
Chroma (*C**)	54.6	43.0	48.5	38.7	46.3	29.3	25.5	49.5	-	-	-	-	-	-	Fawole & Opara, 2013e
	-	-	47.9 - 52.7	-	-	-	-	-	-	-	-	-	-	-	Mditshwa *et al.*, 2013
	-	-	-	-	-	-	48.4 - 50.4	-	-	-	-	-	-	-	Fawole & Opara, 2013a
	-	-	-	-	-	-	-	-	44.7	36.7	38.8	15.8	-	-	Al-Said *et al.*, 2009
	-	-	-	-	-	-	-	-	-	-	-	-	39.9 - 44.2	45.1 - 46.5	Shwartz *et al.*, 2009
Hue (*h*°)	29.1	18.7	22.4	27.5	21.8	56.7	14.7	49.5	-	-	-	-	-	-	Fawole & Opara, 2013e
	-	-	28.2 - 35.1	-	-	-	-	-	-	-	-	-	-	-	Mditshwa *et al.*, 2013
	-	-	-	-	-	-	30.6 - 33.1	-	-	-	-	-	-	-	Fawole & Opara, 2013a
	-	-	-	-	-	-	-	-	37.3	73.9	56.3	16.2	-	-	Al-Said *et al.*, 2009
	-	-	-	-	-	-	-	-	-	-	-	-	20.3 - 35.9	31.5 - 46.1	Shwartz *et al.*, 2009

Arakta (Arak), Ganesh (Gane), Herskovitz (Hersk), Mollar de Elche (MdeE), Wonderful (Wond), Jabal 1 (Jab 1), Jabal 2 (Jab 2), Jabal 3 (Jab 3).

Table 3: Textural properties of aril and kernel of pomegranate cultivars grown in South Africa and Oman

	South Africa								Oman				
Property	Acco	Arakta	Bhagwa	Ganesh	Herskovitz	Mollar de Elche	Ruby	Wonderful	Jabal 1	Jabal 2	Jabal 3	Wild	Reference
Aril													
Firmness (N)	74.5	83.3	85.9	85.9	79.8	80.9	72.4	118.4	-	-	-	-	Fawole & Opara, 2013e
	-	-	88.4 - 98.8	-	-	-	-		-	-	-	-	Mditshwa *et al*., 2013
	-	-	-	-	-	-	-	127.30	-	-	-	-	Arendse *et al*., 2014a
	-	-	-	-	-	-	90.80 - 92.11	-	-	-	-	-	Fawole & Opara, 2013d
	-	-	-	-	-	-	-	-	9.16	8.22	11.98	14.61	Al-Said *et al*., 2009
Toughness (N mm)	67.8	78.1	77.8	78.5	71.6	90.3	60.6	118.0	-	-	-	-	Fawole & Opara, 2013e
	-	-	-	-	-	-	-	157.46	-	-	-	-	Arendse *et al*., 2014a
	-	-	-	-	-	-	88.82 - 93.71	-	-	-	-	-	Fawole & Opara, 2013d
	-	-	-	-	-	-	-	-	4.42	3.57	5.08	4.19	Al-Said *et al*., 2009
Kernel													
Hardness (N)	70.7	74.8	79.7	67.3	67.2	69.0	66.6	103.6	-	-	-	-	Fawole & Opara, 2013e
	-	-	-	-	-	-	-	-	24.62	27.15	39.90	44.73	Al-Said *et al*., 2009
Toughness (N mm)	39.2	41.0	49.4	38.7	35.2	39.5	36.0	65.6	-	-	-	-	Fawole & Opara, 2013e
	-	-	-	-	-	-	-	-	5.86	6.54	9.91	10.66	Al-Said *et al*., 2009

Chapter 3

Physico-chemical and textural properties relevant to processing of pomegranate fruit and arils

PHYSICO-CHEMICAL AND TEXTURAL PROPERTIES RELEVANT TO PROCESSING OF POMEGRANATE FRUIT AND ARILS

Abstract

Pomegranate fruit has served several important applications in industrial processing and nutrition. Rising from common usage as table fruit to important nutraceutical, pharmaceutical and cosmeceutical products, there is the need to examine the necessary fruit properties such that optimised processing conditions can be put in place to facilitate its processing whilst reducing wastage and losses. In view of this, the physical and textural properties of whole fruit and arils of 'Wonderful', 'Acco' and 'Herskovitz' and their juice's physico-chemical traits were investigated. The CIE colour attributes of pomegranate fruit peel, arils and juice varied considerably among the cultivars. There were however, no significant differences in whole fruit weight, length, diameter, geometric mean diameter, surface area and volume of oblate spheroid, among the cultivars. Wonderful and Herskovitz cultivars contained the highest (61.62%) and the lowest (56.98%) edible fruit part, respectively. 'Acco', however, had the highest juice yield (74.05 mL/100 g arils). In addition, total soluble solids (15.93°Brix) and titratable acidity (1.32% citric acid) were higher in 'Wonderful' and 'Herskovitz' fruit juice, respectively. As cultivar differences distinguished 'Wonderful' from 'Acco' and 'Herskovitz' in the ease of processing, higher compressibility, cutting strength and puncture force were reported for 'Wonderful' than 'Acco' and 'Herskovitz'. Furthermore, the loss of moisture in the fresh arils resulted in a significantly smaller weight and dimensions. However, the aril shape index increased after drying. Similarly, all compressibility characteristics of pomegranate arils significantly increased after drying. In conclusion, the physico-chemical and textural properties of pomegranate fruit investigated in this study serve to discriminate among the selected cultivars and also provide valuable knowledge on the processing of the fruit cultivars.

Keywords: Arils, Textural, Physico-chemical, Pomegranate, Postharvest

1. Introduction

Pomegranates have had an important presence in history. Pomegranate fruit was regarded in Greek mythology as a symbol of life, nuptial and regeneration. In prehistoric Babylonians and present day China, the fruit is valued as a representation of nature's womb, fruitfulness, abundance and posterity (Modi, 1937; Langley, 2000). In Islam, the Qur'an esteems pomegranate as a gift and a heavenly fruit of God (Dahham *et al.*, 2010). Christians acknowledge the fruit as a sign for resurrection and everlasting life (Langley, 2000). To the Persians, the arils of pomegranate conferred invincibility on battle fields in seasons of war (Dahham *et al.*, 2010). Due to their exceptional characteristic health attributes, pomegranate fruits have gained a tremendous attention from growers, processors, nutritionists and consumers (Hess-Pierce & Kader, 2003; Opara *et al.*, 2009; Viuda-Martos *et al*., 2010). The increasing global interest in the fruit and its co-products has advanced its cultivation, production and processing, and encouraged many scientific studies on minimizing postharvest losses, upholding manufacturing high throughput and facilitating the retention of the quality of the final product.

Presently, South Africa, Australia, Argentina and Chile are the leading growers and exporters of pomegranate in the Southern Hemisphere (Brodie, 2009). The production of pomegranate in South Africa is projected to increase by 189% by 2017 (Kotzé, 2012; POMASA, 2012; Hortgro, 2014). According to Hortgro (2014), pomegranate cultivars grown in South Africa are cvs. Wonderful, Acco, Herskovitz, Bhagwa, Ruby, Arakta, Rosy and Shir. However, cvs. Wonderful, Acco and Herskovitz are of commercial interest presently. With a unique leathery peel and internal architecture, processing pomegranate fruit to obtain the edible fraction has always been a challenge and a time-consuming process. Mechanical harvesting, bulk handling, transporting and storage of pomegranate fruits have presented an important need for basic information in the inherent properties of the fruit (Mohsenin, 1970). The ideas of constructing specific equipment or designing processing analysis in handling pomegranate fruit lie in the knowledge of the fruit physical and textural properties (Mohsenin, 1970; Stroshine, 1998; Singh & Reddy, 2006; Aviara *et al*., 2007; Naderiboldaji *et al*., 2008; Ekrami-Rad *et al*., 2011; Mansouri *et al*., 2011; Arshad *et al*., 2014).

Unfortunately, the South African fruit industry has a limited use for its fruit (Khan *et al*., 2015). For instance, processors and nutritionists in South Africa are more concerned about the juice derived from pomegranate, rendering the other fruit parts with sufficient potential for value-addition wasteful. In addition, improper handling and packaging of pomegranate fruit in South Africa have resulted in high incidence of postharvest losses (Fawole & Opara, 2013c). Postharvest losses of pomegranate are profound in the processing of the fruit especially during fruit cutting, aril extraction and juicing and in the disposal of pomegranate marc (Fawole & Opara, 2015). There is therefore the need to investigate the physico-chemical and textural properties of pomegranate fruit cultivated in South Africa. The conclusions of this study may help the South African pomegranate industry to design processing equipment and optimise processing conditions in order to ensure proper handling and packaging of the fruit, as well as minimise pomegranate postharvest losses.

The purpose of this study was to characterise the physical, textural and chemical properties of three major pomegranate cultivars grown in South Africa (‘Wonderful’, ‘Acco’ and ‘Herskovitz’) in order to provide information relevant to processing and nutrition in a quest to assist in cultivar selection for food and industrial purposes.

2. Materials and methods

2.1. Fruit collection and preparation

2.1.1. Fruit collection

Pomegranate fruit cultivars (‘Wonderful’, ‘Acco’, and ‘Herskovitz’) harvested during 2015/2016 season were procured from Sonlia Packhouse, Wellington, South Africa. Hundred fruits free from bruises, cracks or any form of defects were randomly selected and transported to the Postharvest Technology and Research Laboratory and kept at 5°C in a cold storage room for not more than 72 h prior to analysis.

2.1.2. Fruit preparation

Pomegranate fruit were thoroughly washed with distilled water and air dried. After physical measurements of whole fruit, the fruit was cut longitudinally and arils manually separated. Arils were divided into three portions; the first part was stored in zip lock bags at 5°C while the second portion was juiced using a cheesecloth. The third part was dried at 80°C in an oven (PROLAB, South Africa) until there was no change in weight. Fresh samples of pomegranate arils and juice were kept not more than 24 h before analysed.

2.2. Physical properties

2.2.1. Colour attributes

Fruit peel colour along the equatorial axis of each fruit at two opposite spots were recorded in CIE coordinates (L^*, a^*, b^*) using a Minolta Chroma Meter CR-400 (Minolta Corp, Osaka, Japan) after calibration with a white tile background. Similar colour measurements were made on the arils and juice placed in a colourless glass Petri dish. In addition, juice colour absorbance was measured at 520 nm using a Helios Omega spectrophotometer (Thermo Fisher Scientific, Madison, USA). The colour parameter Chroma (C^*) which describes the length of the colour vector in the plane formed by a^* and b^*, and the hue angle (h^o) that determines the position of such vector were calculated according to the following equations:

$$C^* = (a^{*2} + b^{*2})^{1/2} \quad (1)$$

$$h^o = \arctan (b^*/ a^*) \quad (2)$$

The total colour difference (TCD) between the fruit peel (external) and arils and juice (internal) components was calculated as:

$$\text{TCD} = \sqrt{} (L^*_0 - L^*)^2 + (a^*_0 - a^*)^2 + (b^*_0 - b^*)^2 \quad (3)$$

where L^*_0, a^*_0 and b^*_0 are the colour parameters of the peel (reference value), while L^*, a^* and b^* are the colour values of the aril and juice (Al-Said *et al*., 2009; Fawole & Opara, 2013f). Twenty fruits were used and results were the means ± S.E. of determinations obtained (n = 40).

2.2.2. Weight

Pomegranate whole fruit was measured using an electronic balance, Model ML3002E/01 (NewClassic MF, Switzerland) with an accuracy of ± 0.01 g. Furthermore, fifty single fresh and dried arils were randomly hand-picked from a pool of fresh and dried arils and their respective weight recorded using an electronic balance, Model ML104/01, (NewClassic MF, Switzerland) with an accuracy of ± 0.0001 g. The total number of arils per fruit and ratio of edible (arils) to non-edible fractions (peel, membrane and albedo) was also determined. The parameters were presented as mean ± S.E (n = 50).

2.2.3. Lineal dimensions and derivatives

Lineal dimensions including length (L) and diameter (D) of whole fruit and fresh and dried arils, as well as peel thickness were determined using a digital vernier calliper (Mitutoyo, Japan) with an accuracy of ± 0.01 mm. In replicates, volumes of whole fruit and fresh and dried arils were measured using water-displacement technique. Lineal dimensions were used to calculate shape index (SI), aspect ratio (A_R), geometric mean diameter (Dg), sphericity index (φ), surface area (S_F), and volume of oblate spheroid (VSP) using equations 4 – 9, respectively. Volume data were also used to calculate density (d) using equation 10. All parameters were reported as mean ± S.E (n = 50).

$$\text{Shape index, SI} = \frac{L}{D} \quad (4)$$

Aspect ratio, $A_R = \frac{D}{L}$ (5)

Geometric mean diameter, Dg (mm) = $(L \times D^2)^{1/3}$ (6)

Sphericity index, $\varphi = \frac{Dg}{L}$ (7)

Surface area, S_F (cm^2) = $\pi \times Dg^2$ (8)

Volume of oblate spheroid, VSP (cm^3) = $\frac{\pi}{6} \times L \times D^2$ (9)

Density, d ($g\ cm^{-3}$) = $\frac{W}{Vol}$ (10)

Where W is weight of whole fruit or aril and Vol is displaced volume (Mohsenin, 1970; Martínez *et al.*, 2006; Al-Yahyai *et al.*, 2009; Fawole & Opara, 2013f).

2.2.4. Moisture content

Moisture content of pomegranate fruit peel and aril was determined using a gravimetric method according to AOAC 930.15 (AOAC, 2012) with modifications. In five replicates, fruit peel and arils were weighed into clean, dry glass petri dishes and placed in an oven operated at 80°C at 1.0 m/s air velocity. Samples were reweighed until a constant weight was achieved. Moisture content (wet basis) was calculated using equation 11.

$$\text{Moisture content (\%wb)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \qquad (11)$$

2.2.5. Water activity of aril

The water activity of both fresh and dried arils for each cultivar was evaluated in triplicates at 25°C using LabMaster-a_w Analyser, Model CH-8853 (Novasina AG, Switzerland).

2.2.6. Juice chemical attributes

Yield of juice was determined in replicates by manual extraction of 100 g of arils using a cheesecloth. Juice volume was determined by transferring juice into a measuring cylinder. pH values were measured at room temperature using a pH meter (Crison, Barcelona, Spain). Titratable acidity (TA) was determined by titration using a Metrohm 862 compact titrosampler (Herisau, Switzerland). Fresh juice (2 ml) was diluted with Milli-Q water (70 ml) and titrated with 0.1 N NaOH to an endpoint of pH 8.2

and results expressed as grams citric acid/100 ml of juice. Total soluble solids TSS (°Brix) were measured at room temperature using a digital refractometer (Atago, Tokyo, Japan) calibrated with Milli-Q water. TSS:TA was presented as the maturity index (MI), while BrimA, a variant of TSS:TA and a criterion for acceptance of fruit juice, was calculated as BrimA = TSS – k * TA. Where k is the tongue's sensitivity index normally ranging from 2 – 10 (Jordan *et al*., 2001; Jaya & Das, 2002). In this study k value of 2 (k = 2) was used to avoid negative BrimA (Fawole & Opara, 2013a; Fawole & Opara, 2013b; Fawole & Opara, 2013f). All data were reported as mean ± S.E (n = 20).

2.3. Textural properties

2.3.1. Compression test of whole fruit

Fruit compression was performed using a texture profile analyzer XT Plus (Stable MicroSystem, Godalming, UK) with a 70 mm^2, P70 compression platen probe. The texture profile analyzer was calibrated with a 10 kg load cell. The operating conditions were as follows: 1.5 mm/s pre-test speed, 1.0 mm/s probe test speed, 10.0 mm/s post-test speed, 1000 N compression force and 20.0 mm deformation distance.

A single fruit was placed on a steel test platform with the stem calyx axis parallel to the platform and a force deformation curve was obtained for each test. Two variables, force (N) and distance (mm), were obtained using the force deformation curve and the data was interpreted using texture profile analyzer software Exponent v.4 (Stable MicroSystem Ltd., Godalming, UK). The Young's or elastic modulus (N/mm), Firmness (N), toughness (N mm) and bioyield force (N) were calculated by running macro software. The elastic modulus was designated as the fruit tendency to recover elastically from deformation. The firmness was characterised as the maximum force (N) required to compress the fruit to a distance of 20 mm. The toughness (energy) required to compress the fruit was determined by calculating the area under the force deformation curve. The bioyield point was considered as the force beyond which there was permanent deformation (Appendix: Chapter 3, Fig. 1A). Fruit compression test was carried out on 20 individual fruits of similar sizes and the results were presented as mean ± S.E (Fawole & Opara, 2013f; Arendse, 2014).

2.3.2. Cutting test of whole fruit

Texture profile analyser XT Plus (Stable MicroSystem, Godalming, UK) were used with a blade set knife (3 mm thick; 70 mm width; 100 mm height; 45° chisel end and a bell lock). For each test, a single pomegranate fruit was positioned with its stem calyx axis parallel to the platform. The operating conditions for the profile analyzer were as follows: 1.0 mm/s pre-test speed, 1.0 mm/s cutting test speed, 10.0 mm/s post-test speed, 1000 N cutting force and 25.0 mm cutting distance. The data obtained from the textural profile analyzer was interpreted using software Exponent v.4. The software was used to run macro which was used to evaluate the fruit firmness (N), toughness (N mm), elastic modulus (N/mm) and cutting force (N) (Appendix: Chapter 3, Fig. 1B). Fruit cutting test was carried out on 20 randomly selected fruits of similar sizes and the data expressed as mean ± S.E (Fawole & Opara, 2013f; Arendse, 2014).

2.3.3. Puncture resistance test of whole fruit

Fruit texture analyzer (GÜSS-FTA, model GS, South Africa) was used to measure puncture resistance of pomegranate fruit. A 5.0 mm cylindrical probe was programmed to puncture 10.0 mm into the fruit at the speed of 10.0 mm/s on a steel test platform with the fruit stem calyx axis parallel to the platform. Duplicate tests were performed on opposite sides on the equilateral region of 20 individual fruits of similar sizes. The puncture resistance (peak force required to puncture the fruit) and its corresponding energy were recorded and presented as mean ± S.E (Arendse, 2014).

2.3.4. Compression test of aril

Fresh and dried pomegranate aril compression test was performed using a texture profile analyzer XT Plus (Stable MicroSystem Ltd., Godalming, UK), with a 35.0 mm diameter cylindrical compression probe. Compression test was performed on individual arils with the following operating conditions: 1.5 mm/s pre-test speed, 1.0 mm/s probe test speed, 10.0 mm/s post-test speed, 10.0 N compression force and 10.0 mm compression distance. The data obtained from the textural analyzer was interpreted using software Exponent v.4 (Stable MicroSystem Ltd., Godalming, UK). The software was then used to run macro which gave the elastic modulus (N/mm), rupture force (N) (fresh arils), firmness/hardness (N) (fresh/dried arils, respectively), toughness (N mm) and bioyield force (N) (Appendix: Chapter 3, Fig. 2). Aril compression test was performed on 50 randomly selected arils and the results were presented as mean ± S.E (Fawole & Opara, 2013f; Arendse, 2014).

3. Statistical analysis

Statistica 64, version 13 was used to calculate Analysis of Variance (ANOVA) for the fruit properties. ANOVA served to determine whether there were any statistically significant interactions between means of dependent and independent variables. The observed, weighted means of the studied parameters were also subjected to Duncan Multiple Range Test (DMRT) with a statistical significance of 5% confidence level. DMRT provided significance levels for the differences among means of any fruit property. Correlations and associations among all examined properties of pomegranate whole fruit, fresh and dried arils and pomegranate juice were determined using XLSTAT Principal Component Analysis (PCA), version 2012.04.1 (Addinsoft, France).

4. Results and discussion

4.1. Physical properties

4.1.1. Colour attributes of fruit peel and arils

Pomegranate whole fruit, aril and juice redness is a desirable quality attribute for processors and consumers. The colour attributes of the investigated pomegranate cultivars are shown in Table 1. Fruit peel, aril and juice colour varied significantly ($p < 0.05$) in the colour parameters L^*, a^*, b^*, C^* and h^o, among the pomegranate cultivars. The observed variation was not surprising as the colours and intensity of fruit peel, aril and juice visibly differed. Pomegranate fruit colour is another important factor affecting marketability and consumer preference (Opara *et al*., 2009). The CIE a^* (+) value, which indicates the redness of the fruit peel ranged between 38.16 and 46.33. These values correspond with visual variation observed among appearance of the studied cultivars, ranging from light red (‘Wonderful’) to dark red (‘Acco’). Peel lightness (L^*) was the highest for ‘Herskovitz’ while the lowest was measured for ‘Acco’. Nonetheless, there were no significant differences between peel lightness of Wonderful and Herskovitz cultivars. Fruit peel colour intensity (C^*) varied as ‘Acco’ and ‘Herskovitz’ differed significantly from ‘Wonderful’. On the other hand, lower values were obtained for the aril and juice colour components. This is in agreement with previous studies that there is no correlation between pomegranate peel colour and aril or juice colour (Al-Said *et al*., 2009; Holland *et al*., 2009).

Whilst the colour attributes of pomegranate fruit juice were consistent with those of Shwartz *et al*. (2009), higher colour characteristics were described for juice of pomegranate varieties grown in Turkey (Turfan *et al*., 2011) and Spain (Mena *et al*., 2011; Mena *et al*., 2013). The juice absorbance, which was distinctly lower for Herskovitz cultivar, may be attributed to the concentration of anthocyanins (Shulman *et al*., 1984). These studies further showed that the L^* value of arils of ‘Acco’, which corresponded with its less red visual appearance was the lowest among the cultivars. The variation in redness of fruit peel was higher than the aril and juice among the cultivars. Considering the total colour difference (TCD), the significant differences ($p < 0.05$) among the cultivars separated 'Acco' and 'Herskovitz' from 'Wonderful'.

4.1.2. Weight, lineal dimensions and derivatives

4.1.2.1. Whole fruit

Physical properties of the examined pomegranate cultivars are shown in Table 2. There were no significant differences observed for the properties studied, except for fruit volume. Fruit volume was biggest in 'Acco' and smallest in 'Wonderful'. Fruit weight is vital in pomegranate fruit production and marketing since it drives consumer preference (Hess-Pierce & Kader, 2003; Holland *et al.*, 2009). Pomegranate fruit weight varied between 344.53 to 353.86 g. These weights are within the ranges (196.89 – 524.02 g) reported in previous studies for different pomegranate cultivars (Opara *et al.*, 2009; Zarei *et al.*, 2010; Tehranifar *et al.*, 2010; Fawole & Opara, 2013f). The data of the investigated physical properties showed how closely related the three examined fruit cultivars harvested in South Africa are; hence making its postharvest handling easier. The measured physical properties are convenient in designing and optimising equipment for postharvest handling and processing (Stroshine, 1998; Sirisomboon *et al.*, 2007; Athmaselvi *et al.*, 2014).

Pomegranate peel thickness varied between 2.65 – 3.35 mm, with Wonderful and Herskovitz cultivars forming the extremes, respectively (Table 2). The present study was in agreement with Al-Said *et al*. (2009) and Fawole & Opara (2013f). Interestingly, it was observed that the thickest peel corresponded with the highest peel moisture content and vice versa. However, there were no significant differences between the moisture content of the fruit peels. The thickness and moisture content of the fruit peel may contribute to the larger compression forces and energy required to break the whole fruit. Pomegranate peel moisture content in this study was consistent to the findings of Arendse *et al*. (2014c).

Pomegranate fruit is mainly explored because of its edible arils, which are used extensively in food and beverage industries. Pomegranate arils constituted over 50% of the total fruit weight for all the investigated cultivars (Table 2). In particular, 'Wonderful', 'Acco' and 'Herskovitz' had 61.62%, 59.66% and 56.98% aril portion, respectively. The ratio of non-edible to edible part revealed that

Wonderful cultivar had less waste compared to ‘Acco’ and ‘Herskovitz’. These data are in agreement Al-Maiman & Ahmad (2002); Al-Said *et al*. (2009); Fawole & Opara (2013a) and Fawole & Opara (2013f). However, the varying edible percentages reported for other pomegranate fruit cultivars (Riyahi *et al*., 2011; Mditshwa *et al*., 2013) may be explained by cultivar differences and influence of climatic conditions of growing region and agricultural practices and fertilizer applications adapted on pomegranate farmlands.

4.1.2.2. Aril

As explained earlier, the edible portion of pomegranate fruits consists of the aril which contains the juice and the kernel. There were no significant differences in the total number of arils per fruit for the studied cultivars (Table 3). Optimizing the processing conditions of the arils is the goal of processors and nutritionists (Martínez *et al*., 2006; Hasnaoui *et al*., 2011). As presented in Table 3, many physical properties of fresh and dried arils of the investigated pomegranate cultivars were found to be statistically ($p < 0.05$) different. Packaging, transport and processing of pomegranate arils requires knowledge of their physical properties (Arshad *et al*., 2014). As expected, the loss of moisture in drying significantly decreased the arils weight per fruit. This may imply more packing of dried arils per bag as implicated in ‘anardana’. Factorial analysis indicated cultivar and drying as the factors influencing weight of arils per fruit. The weight of individual arils differed substantially with Wonderful and Acco cultivars showing the highest and the lowest values, respectively, with the interactions between cultivar and drying ($p < 0.0001$) contributing to the observed variations. Furthermore, significant differences were observed among the cultivars and between the processed states for lineal dimensions and derivatives of both fresh and dried arils of pomegranate cultivars.

Both fresh and dried arils of ‘Herskovitz’ had the smallest volume and the highest density. Variations in these parameters are attributed to differences in cultivar and/or drying of the arils (Table 3). Drying also resulted in significant reduction in aril length, diameter and the other derived properties including aspect ratio, sphericity index, surface area, geometric mean diameter and volume of oblate spheroid (Table 3). An increase in shape index was however observed after drying. This implied that shrinkage in aril diameter was more pronounced than that of aril length. According to the factorial analysis, there were significant interactions between cultivar and drying ($p < 0.0001$) for aril length, diameter and the other reported derived properties. The physical properties of fresh arils described in Table 3 were consistent with literature (Al-Said *et al*., 2009; Riyahi *et al*., 2011; Mditshwa *et al*., 2013;

Fawole & Opara, 2013f). Furthermore, the provision of data on dried arils of the examined cultivars grown in South Africa may be of relevance to processors and nutritionists exploiting the cultivars for the greatest benefit to mankind.

4.1.3. Water activity of aril

As illustrated in Table 3, there were no statistical differences in water activity evaluated in fresh arils of pomegranate cultivars. However, the water activity of dried arils was considerably higher for ‘Wonderful’. In spite of that, the water activity of all dried arils was below the limit implicated to support spoilage (Velíšek, 2014).

4.1.4. Juice chemical attributes

The juice yield and their chemical composition are presented in Table 4. High juice yield is a desirable attribute for processors, nutritionists and consumers. There were significant differences in the juice yield of the studied cultivars, ranging from 67.75 to 74.05 (mL per 100 g arils), with Acco and Herskovitz cultivars having the highest and the lowest amount of juice, respectively. The juice yield obtained in the present study were higher than those reported for other cultivars (Al-Maiman & Ahmad, 2002; Al-Said *et al*., 2009; Mena *et al*., 2011; Fawole *et al*., 2013; Fawole & Opara, 2013a; Fawole & Opara, 2013d; Fawole & Opara, 2013e; Fawole & Opara, 2013f; Arendse *et al*., 2014a; Arendse *et al*., 2014b). This discrepancy may be largely due to differences in juice extraction methods as well as pomegranate cultivar and fruit maturity. Total soluble solids (TSS) in the investigated pomegranate juice varied significantly from 13.48 to 15.93 (ºBrix), with the highest and the lowest content in ‘Wonderful’ and ‘Herskovitz’, respectively. These values are consistent with the ranges (13.23 – 17.62 ºBrix) reported for pomegranate accessions grown in Spain (Mena *et al*., 2011). However, higher TSS ranges (15.77 – 19.56 ºBrix) have been reported for pomegranate cultivars grown in Iran (Zarei *et al*., 2010).

The pH values ranged between 3.51 (‘Acco’) and 3.88 (‘Wonderful’) (Table 4). Lower pH values imply shorter time and lower temperature combination required for industrial pasteurization of pomegranate juice (Fellows, 2009). Titratable acidity (citric acid) was highest in ‘Herskovitz’ (1.32%), which was 3-folds more acidic than ‘Acco’ (0.41%). The juice acidity level, which determines consumer perceptions of sweetness and sourness, can be attributed to the fruit genetic make-up (Holland *et al*., 2009). The sugar:acid ratio (TSS:TA) plays a major role in taste perceptions of pomegranate juice. Based on this, pomegranate cultivars may be classified as sour, sour-sweet and sweet (Martínez *et al*., 2006; Tehranifar *et al*., 2010; Hasnaoui *et al*., 2011). The TSS:TA ratio is also applicable in assessing fruit quality and ripeness (Hasnaoui *et al*., 2011). This ratio is also important for the selection of fruit cultivar in the food and beverage industries as fruit cultivars with low TSS:TA ratio are preferred for food and juice formulations (Al-Said *et al*., 2009). The values obtained ranged from 14.83 ('Herskovitz') to 36.44 ('Acco') (Table 4) and these were in agreement with literature (Mena *et al*., 2011; Fawole & Opara, 2013f). Based on this attribute, the investigated cultivars can be classified as sour ('Wonderful' and 'Herskovitz') and sour-sweet ('Acco'). The BrimA index, which is a variant to TSS:TA and more reliable in predicting fruit taste and flavour, was also derived. Similar to TSS:TA, this followed the order of 'Acco' > 'Wonderful' > 'Herskovitz'.

4.2. Textural properties

4.2.1. Compressibility of whole fruit

During postharvest packaging and transporting of pomegranate fruit, the fruit to a greater extent may undergo compression. This results in undesirable chemical changes in fruit and spoilage. The compressibility of pomegranate whole fruit revealed four characteristic textural properties (Table 5). Whole fruit firmness (390.60 N) and bioyield (124.53 N) were highest in Wonderful cultivar. However, 'Wonderful' had the lowest fruit toughness (2385.02 N mm). There were no significant differences in the elastic modulus among the fruit cultivars. The variations in fruit compressibility may be due to cultivar differences in peel fibre network, thickness and moisture content (Fawole & Opara, 2013f). Fruit resistance to compression is a measure of the interfacial toughness of its peel (Thouless & Yang, 2008).

4.2.2. Cutting strength of whole fruit

Due to the complex architecture of pomegranate fruit, extracting arils from the fruit remains critical in nutrition and industrial processing. The cutting strength of pomegranate fruit was conducted to inform processors and nutritionists the first line of economic importance with regards to its processing. Whole fruit firmness (208.62 N) and cutting force (94.75 N) were highest in Wonderful cultivar. In contrast, the cutting force for 'Acco' (35.39 N) was the smallest. There were however no significant differences in the toughness of the fruit although the highest toughness was accounted for in 'Wonderful' (Table 5). Again, this may be attributed to the structural integrity of pomegranate peel (Holland *et al*., 2009).

4.2.3. Puncture resistance of whole fruit

The ability of pomegranate fruit to resist puncture is paramount in the designing harvesting tools and equipment and packages. As presented in Table 5, the puncture resistance (98.33 N) and the puncture energy (0.48 J) were all highest for ‘Wonderful’. This may be attributed to the relatively thinner peel of Wonderful fruit cultivar, which contained the highest moisture content, thus forming a stronger fibre network making it more resilient to puncture (Holland *et al*., 2009). Acco and Herskovitz fruit cultivars exhibited a distinctly similar pattern as both cultivars were largely susceptible to puncture. Knowledge of pomegranate fruit puncture resistance could be used in the improvement of harvest practices, transport and postharvest handling of the fruit cultivars (Fawole & Opara, 2013f). Whilst the puncture resistance of the examined fruit cultivars was consistent with the findings of Fawole & Opara (2013f), much higher forces were reported by Arendse *et al*. (2014c). This may be due to varying maturity stages and harvesting times for pomegranate fruit at the time of the study.

4.2.4. Compressibility of aril

Textural properties of pomegranate arils constitute an important quality parameter in pomegranate industry (Szychowski *et al.*, 2015). As presented in Table 6, the compressibility of pomegranate arils varied significantly ($p < 0.05$) among the cultivars and between the processed states. Among the fresh arils, there were no significant differences among the cultivars although ‘Wonderful’ was the firmest. Aril hardness is an indispensable property that drives consumer preference (Al-Said *et al.*, 2009; Hasnaoui *et al.*, 2011; Szychowski *et al.*, 2015). Aril hardness increased after drying for all cultivars albeit the dried arils of ‘Wonderful’ and ‘Acco’ were harder than arils of ‘Herskovitz’. Similarly, toughness was highest for both fresh and dried arils of ‘Wonderful’. There were significant interaction effects ($p < 0.0001$) between cultivar and drying for both aril hardness and toughness (Table 6), thus making it inconclusive on factors that influenced the hardness and toughness of the aril. In comparison, hardness and toughness of fresh arils in this study were higher than those reported for fresh arils of fruit cultivars harvested in Oman (hardness = 8.22 – 14.61 N; toughness = 3.57 – 5.08 N mm) (Al-Said *et al.*, 2009) and South Africa (hardness = 72.4 – 127.3 N; toughness = 60.6 – 157.4 N mm) (Fawole & Opara, 2013b).

Aril rupture force is the maximum force required to completely release all the juice from the aril. This rupture force, which is independent on the kernel inside the aril, is reliant on the aril membrane integrity, as well as the turgor pressure built inside the aril. This may be the reason for the higher rupture forces of ‘Wonderful’ (40.62 N) and ‘Herskovitz’ (40.74 N). In contrast, the aril of ‘Acco’ burst with a relatively lower compressibility force (35.59 N) (Table 6). These data were lower than the rupture forces of Iranian ‘Poost Sefid’ (52.1 - 198.0 N) and ‘Malas-Yazd’ (85.0 - 307.5 N) (Tarighi *et al*., 2011). During processing and packaging of fresh arils, much attention should therefore be given to ‘Acco’ such that the arils are technically relieved of compression. Processors and nutritionists may therefore have to depend on more solid packages for storage and transport to consumers.

Within the fresh and dried state arils, there were no significant differences in the bioyield force and elastic modulus of the arils. Drying significantly resulted in higher bioyield force and elastic modulus. This may be attributed to the formation of the solid, glassy, dehydrated membrane that surrounds the kernel of a dried aril. Factorial analysis revealed the bioyield force and elastic modulus to be dependent on drying of the arils ($p < 0.0001$).

4.5. Multivariate result

4.5.1. Pearson correlation result

Correlations among pomegranate fruit properties are presented in Appendix: Chapter 3, Table 1. Positive correlations suggest direct relations, whereas negative correlations describe inverse relations between the properties. For instance, a strong negative correlation (r = -0.999) between whole fruit weight and elastic modulus (whole fruit under compression) implied that fruit with bigger weight had a lower ability to recover from compression. Similarly, a negative correlation (r = -1.000) between whole fruit volume and firmness (whole fruit under compression) also meant that bigger fruit volume can be associated with poor firmness (whole fruit under compression). On the contrary, higher cutting force can be associated with pomegranate fruit of bigger density (r = 1.000). In addition, a positive correlation (r = 1.000) between pomegranate whole fruit with bigger surface area and toughness (whole fruit under compression) was also observed. Fruit peels with high moisture content also implied high edible fruit part (%) (r = 1.000). More edible fruit part (%) also meant higher juice total soluble solids content (r = 1.000). Furthermore, juice yield negatively correlated (r = -0.997) with titratable acidity.

4.5.2. Principal Component Analysis result

The characteristic attributes of whole fruit, arils and juice of Wonderful, Acco and Herskovitz pomegranate cultivars are presented on a Principal Component Analysis (PCA) biplot (Fig. 1.). Factors

1 and 2 (F1 and F2) accounted for 61.38% and 38.62% variations in the investigated cultivars, respectively. In general, Acco cultivar is characterised by high fresh aril moisture and juice yield, TSS:TA, and whole fruit weight and volume. ‘Herskovitz’ is associated with high juice lightness, peel thickness, number of arils per fruit and non-edible fraction whereas cv. Wonderful is characterised by high lineal dimensions and derivatives and several textural parameters (Fig. 1).

5. Conclusions

The CIE colour attributes of pomegranate fruit peel, arils and juice varied considerably among the cultivars. Larger total colour difference between the investigated fruit parts was consistently evaluated for Acco and Herskovitz cultivars. Except for whole fruit weight, length, diameter, geometric mean diameter, surface area and volume of oblate spheroid, all other physical properties varied considerably among the fruit cultivars. Wonderful and Herskovitz cultivars were characterized by high edible and non-edible fruit part, respectively. In addition, over 65 mL/100 g arils of juice were derived for all fruit cultivars with ‘Acco’ given the highest juice yield (74.05 mL/100 g arils). Total soluble solids and titratable acidity were higher in ‘Wonderful’ and ‘Herskovitz’ fruit juice, respectively. In terms of ease of processing, ‘Wonderful’ fruit would require higher compressibility, cutting strength and puncture force than ‘Acco’ and ‘Herskovitz’. Furthermore, as expected, dried pomegranate arils had a significantly smaller weight and dimensions. However, aril shape index increased after drying. Also, the compressibility characteristics of pomegranate arils significantly increased after drying. Cultivar differences, which clearly distinguished ‘Wonderful’ from ‘Acco’ and ‘Herskovitz’, influenced the ease of processing.

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Table 1: Colour attributes of fruit peel, aril and juice of three commercial pomegranate cultivars grown in South Africa

Fruit part	Cultivar		
Colour attribute	Wonderful	Acco	Herskovitz
Peel			
L^*	50.04 ± 1.29^{a}	45.71 ± 0.85^{b}	52.82 ± 1.12^{a}
a^*	38.16 ± 1.01^{c}	46.33 ± 0.35^{a}	43.06 ± 0.83^{b}
b^*	29.22 ± 0.79^{a}	25.26 ± 0.52^{b}	27.56 ± 0.50^{a}
C^*	48.59 ± 0.57^{b}	52.87 ± 0.35^{a}	51.29 ± 0.71^{a}
h°	37.73 ± 1.40^{a}	28.57 ± 0.57^{c}	32.81 ± 0.76^{b}
Aril			
L^*	12.84 ± 1.03^{a}	7.72 ± 0.78^{b}	10.79 ± 1.28^{a}
a^*	15.99 ± 0.82^{a}	14.25 ± 0.83^{a}	14.98 ± 0.83^{a}
b^*	7.77 ± 0.49^{a}	6.63 ± 0.60^{a}	6.67 ± 0.50^{a}
C^*	17.82 ± 0.92^{a}	15.75 ± 0.99^{a}	16.47 ± 0.90^{a}
h°	25.81 ± 0.88^{a}	24.36 ± 0.90^{a}	23.85 ± 1.35^{a}
Juice			
L^*	33.84 ± 0.58^{b}	34.20 ± 0.15^{b}	35.60 ± 0.21^{a}
a^*	4.73 ± 0.30^{a}	3.40 ± 0.16^{b}	3.37 ± 0.18^{b}
b^*	0.52 ± 0.11^{a}	0.45 ± 0.04^{a}	0.15 ± 0.05^{b}
C^*	4.77 ± 0.31^{a}	3.44 ± 0.16^{b}	3.38 ± 0.18^{b}
h°	5.17 ± 1.12^{a}	7.24 ± 0.49^{a}	1.45 ± 1.37^{b}
Absorbance (520 nm)	3.25 ± 0.01^{a}	3.30 ± 0.01^{a}	3.12 ± 0.05^{b}
Total colour difference (TCD)			
TCD (fruit peel and aril)	49.80 ± 1.65^{b}	55.11 ± 1.80^{a}	55.55 ± 1.17^{a}
TCD (fruit peel and juice)	48.22 ± 0.84^{b}	51.42 ± 0.74^{a}	51.87 ± 0.58^{a}
TCD (aril and juice)	25.28 ± 1.09^{b}	29.91 ± 0.52^{a}	28.55 ± 1.08^{a}

Values followed by different letters in the same row are significantly different at 5% level by Duncan Multiple Range Test.

Table 2: Physical properties of whole fruit of three pomegranate cultivars harvested in South Africa

	Cultivar		
Property	Wonderful	Acco	Herskovitz
Weight (g)	346.14 ± 11.03^{a}	353.86 ± 9.43^{a}	344.53 ± 9.34^{a}
Volume (cm^{3})	263.50 ± 9.06^{c}	326.60 ± 9.42^{a}	296.30 ± 10.69^{b}
Density (g/cm^{3})	1.32 ± 0.01^{a}	1.08 ± 0.00^{b}	1.16 ± 0.01^{ab}
Length (mm)	83.05 ± 0.61^{a}	82.14 ± 0.62^{a}	81.35 ± 0.56^{a}
Diameter (mm)	91.37 ± 0.54^{a}	92.73 ± 0.68^{a}	93.04 ± 0.78^{a}
Shape index	0.91 ± 0.01^{a}	0.89 ± 0.01^{b}	0.88 ± 0.01^{b}
Aspect ratio	1.10 ± 0.01^{b}	1.13 ± 0.01^{a}	1.14 ± 0.01^{a}
Geometric mean diameter (mm)	84.61 ± 0.46^{a}	85.11 ± 0.47^{a}	85.04 ± 0.59^{a}
Sphericity index	1.02 ± 0.00^{b}	1.04 ± 0.01^{a}	1.05 ± 0.01^{a}
Surface area (cm^{2})	225.02 ± 2.42^{a}	227.72 ± 2.55^{a}	227.51 ± 3.08^{a}
Volume of oblate spheroid (cm^{3})	363.83 ± 5.95^{a}	370.51 ± 6.34^{a}	370.32 ± 7.48^{a}
Peel thickness (mm)	2.65 ± 0.10^{b}	3.25 ± 0.18^{a}	3.35 ± 0.17^{a}
Peel moisture content (%wb)	70.73 ± 9.25^{a}	66.56 ± 5.37^{a}	63.59 ± 2.69^{a}
Non-edible weight (g)	144.49 ± 6.28^{b}	149.58 ± 7.55^{ab}	157.41 ± 7.73^{a}
Non-edible (%)	38.38 ± 1.14^{b}	40.34 ± 1.14^{ab}	43.02 ± 1.38^{a}
Edible weight (g)	229.56 ± 6.99^{a}	214.87 ± 5.78^{ab}	203.85 ± 6.05^{b}
Edible (%)	61.62 ± 1.14^{a}	59.66 ± 1.14^{ab}	56.98 ± 1.38^{b}
Non-edible **:** Edible	0.64 ± 0.03^{b}	0.69 ± 0.03^{ab}	0.79 ± 0.04^{a}

Values followed by different letters in the same row are significantly different at 5% level by Duncan Multiple Range Test.

Table 3: Physical properties of fresh and dried arils of three pomegranate fruit cultivars grown in South Africa

	Cultivar								
	Wonderful		Acco		Herskovitz		Cultivar	Drying	Cultivar × Drying
Property	Fresh	Dried	Fresh	Dried	Fresh	Dried	**(A)**	**(B)**	**(A × B)**
Weight of arils per fruit (g)	229.56±6.99^{a}	48.04±3.17^{c}	214.87±5.78^{b}	36.21±1.75^{c}	203.82±6.05^{b}	33.64±1.69^{c}	<0.0001	<0.0001	0.0530
Aril weight (g)	0.36±0.01^{a}	0.08±0.00^{d}	0.34±0.00^{b}	0.06±0.00^{e}	0.23±0.01^{c}	0.06±0.00^{e}	<0.0001	<0.0001	<0.0001
Volume (cm^{3})	0.80±0.05^{a}	0.36±0.02^{d}	0.68±0.04^{b}	0.21±0.02^{e}	0.54±0.02^{c}	0.19±0.01^{e}	<0.0001	<0.0001	0.1665
Density (g/cm^{3})	0.49±0.06^{a}	0.19±0.03^{c}	0.49±0.03^{a}	0.30±0.04^{b}	0.50±0.01^{a}	0.30±0.02^{b}	0.1604	<0.0001	0.1728
Length (mm)	10.37±0.11^{a}	8.19±0.12^{c}	10.29±0.09^{a}	7.97±0.09^{c}	9.17±0.08^{b}	7.60±0.08^{d}	<0.0001	<0.0001	<0.0001
Diameter (mm)	7.34±0.10^{a}	5.18±0.13^{c}	7.36±0.09^{a}	4.42±0.09^{d}	6.27±0.09^{b}	4.53±0.08^{d}	<0.0001	<0.0001	<0.0001
Shape index	1.42±0.02^{c}	1.63±0.05^{b}	1.41±0.02^{c}	1.84±0.04^{a}	1.47±0.02^{c}	1.70±0.03^{b}	<0.0001	<0.0001	<0.0001
Aspect ratio	0.71±0.01^{a}	0.64±0.02^{b}	0.72±0.01^{a}	0.56±0.01^{d}	0.69±0.01^{a}	0.60±0.01^{c}	<0.0001	<0.0001	<0.0001
Geo mean D (mm)	8.05±0.08^{a}	5.90±0.09^{c}	8.05±0.07^{a}	5.27±0.07^{d}	6.98±0.08^{b}	5.28±0.07^{d}	<0.0001	<0.0001	<0.0001
Sphericity index	0.78±0.01^{a}	0.73±0.02^{b}	0.78±0.01^{a}	0.66±0.01^{d}	0.76±0.01^{a}	0.70±0.01^{c}	<0.0001	<0.0001	<0.0001
Surface area (cm^{2})	2.05±0.04^{a}	1.10±0.03^{c}	2.04±0.04^{a}	0.88±0.02^{d}	1.54±0.03^{b}	0.88±0.02^{d}	<0.0001	<0.0001	<0.0001
VSP (cm^{3})	0.30±0.01^{a}	0.12±0.01^{c}	0.29±0.01^{a}	0.08±0.00^{d}	0.19±0.01^{b}	0.08±0.00^{d}	<0.0001	<0.0001	<0.0001
Water activity	0.97±0.00^{a}	0.31±0.00^{b}	0.97±0.00^{a}	0.29±0.00^{c}	0.97±0.00^{a}	0.29±0.00^{c}	<0.0001	<0.0001	<0.0001

Number of arils per fruit: 614.20±57.68^{a} (‘Wonderful’); 645.50±40.45^{a} (‘Acco’); 742.40±40.39^{a} (‘Herskovitz’).

Values followed by different letters in the same row are significantly different at 5% level by Duncan Multiple Range Test.

Red ink designates a significant level and hence a determining factor.

Geometric mean diameter (Geo mean D). Volume of oblate spheroid (VSP).

Table 4: Chemical properties of pomegranate juice of three pomegranate cultivars grown in South Africa

	Cultivar		
Property	Wonderful	Acco	Herskovitz
Yield (mL/100 g arils)	70.20 ± 1.41^{ab}	74.05 ± 1.02^{a}	67.75 ± 1.65^{b}
pH	3.88 ± 0.03^{a}	3.51 ± 0.02^{b}	3.57 ± 0.10^{b}
Total soluble solids (°Brix)	15.93 ± 0.18^{a}	14.90 ± 0.10^{b}	13.48 ± 0.24^{c}
Titratable acidity (% citric acid)	1.03 ± 0.03^{b}	0.41 ± 0.01^{c}	1.32 ± 0.13^{a}
TSS **:** TA	15.80 ± 0.54^{b}	36.44 ± 0.66^{a}	14.83 ± 2.48^{b}
BrimA	13.87 ± 0.20^{a}	14.08 ± 0.10^{a}	10.84 ± 0.33^{b}

Values followed by different letters in the same row are significantly different at 5% level by Duncan Multiple Range Test.

Table 5: Textural properties of whole fruit of three pomegranate cultivars grown in South Africa

	Cultivar		
Property	Wonderful	Acco	Herskovitz
Compressibility			
Firmness (N)	390.60 ± 5.29^{a}	312.05 ± 13.82^{b}	336.27 ± 7.65^{b}
Toughness (N mm)	2385.02 ± 115.70^{b}	3102.06 ± 263.29^{a}	3077.57 ± 128.96^{a}
Bioyield (N)	124.53 ± 24.03^{a}	61.92 ± 12.96^{b}	85.16 ± 17.34^{ab}
Elastic modulus (N/mm)	19.93 ± 1.90^{a}	17.79 ± 1.20^{a}	20.51 ± 4.51^{a}
Cutting strength			
Firmness (N)	208.62 ± 21.86^{a}	138.41 ± 7.90^{b}	163.84 ± 6.56^{b}
Toughness (N mm)	1620.60 ± 213.68^{a}	1201.44 ± 100.08^{a}	1329.68 ± 83.38^{a}
Cutting force (N)	94.75 ± 18.07^{a}	35.39 ± 6.41^{b}	80.28 ± 7.80^{a}
Elastic modulus (N/mm)	11.61 ± 1.44^{a}	12.80 ± 2.42^{a}	10.91 ± 1.55^{a}
Puncture resistance			
Puncture resistance (N)	98.33 ± 4.09^{a}	75.45 ± 3.29^{b}	81.65 ± 2.80^{b}
Puncture energy (J)	0.48 ± 0.02^{a}	0.41 ± 0.02^{b}	0.41 ± 0.01^{b}

Values followed by different letters in the same row are significantly different at 5% level by Duncan Multiple Range Test.

Table 6: Textural properties of fresh and dried arils of three pomegranate fruit cultivars grown in South Africa

	Cultivar								
	Wonderful		Acco		Herskovitz		Cultivar	Drying	Cultivar × Drying
Property	Fresh	Dried	Fresh	Dried	Fresh	Dried	**(A)**	**(B)**	**(A × B)**
Firmness or hardness (N)	83.76±1.69^{c}	247.53±5.15^{a}	75.53±1.46^{c}	253.98±6.76^{a}	79.67±1.59^{c}	220.50±5.06^{b}	<0.0001	<0.0001	<0.0001
Toughness (N mm)	109.83±2.42^{d}	281.65±8.43^{a}	89.00±1.63^{e}	263.98±9.96^{b}	95.60±2.24^{de}	215.26±6.75^{c}	<0.0001	<0.0001	<0.0001
Bioyield (N)	4.99±0.35^{b}	30.21±6.67^{a}	6.01±0.40^{b}	37.79±5.38^{a}	5.02±0.25^{b}	31.75±4.88^{a}	0.5250	<0.0001	0.6957
Elastic modulus (N/mm)	4.55±0.25^{b}	59.58±6.84^{a}	4.63±0.28^{b}	52.51±5.07^{a}	4.01±0.17^{b}	64.48±6.06^{a}	0.4089	<0.0001	0.3370

Fresh aril rupture force (N): 40.62±1.51^{a} ('Wonderful'); 35.59±1.34^{b} ('Acco'); 40.74±1.37^{a} ('Herskovitz').

Values followed by different letters in the same row are significantly different at 5% level by Duncan Multiple Range Test.

Red ink designates a significant level and hence a determining factor.

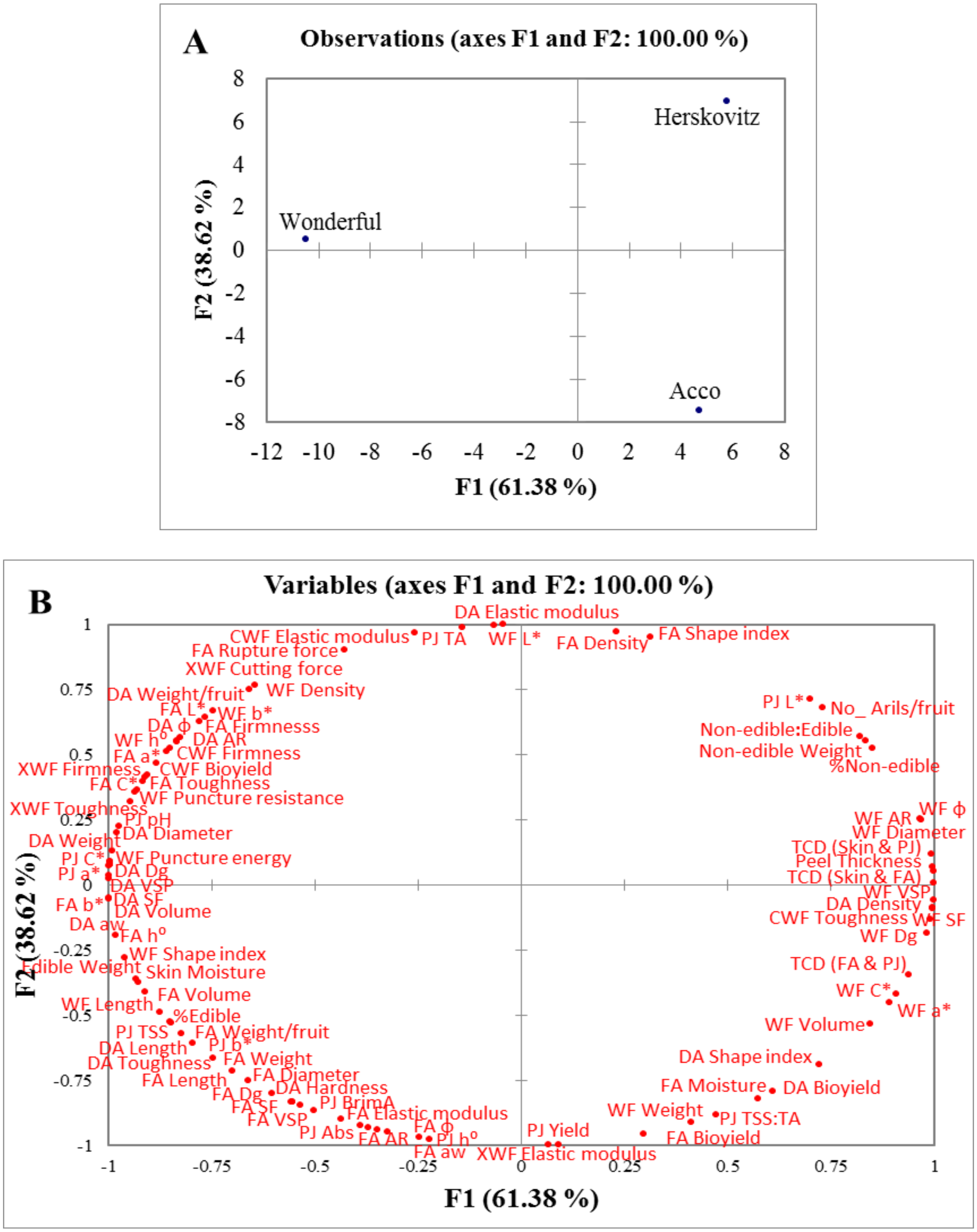

Fig. 1. Principal Component Analysis of F1 and F2 factors showing dispersion of pomegranate fruit cultivars based on measured fruit properties; variable plot (**A**) and observation score (**B**)

Whole fruit (WF), Compressibility of whole fruit (CWF), Cutting strength of whole fruit (XWF), Fresh aril (FA), Dried aril (DA), Pomegranate juice (PJ), Aspect ratio (A_R), Geometric mean diameter (Dg), Sphericity index (φ), Surface area (S_F), Volume of oblate spheroid (VSP), Number of arils per fruit (No_Arils/fruit), Water activity (a_w), Titratable acidity (TA), Total soluble solids (TSS), Lightness (*L**), Redness (*a**), Yellowness (*b**), Chroma (*C**), Hue angle (*h*°), Absorbance (Abs), Total colour difference (TCD).

Chapter 4

Physico-textural and nutritional properties of pomegranate kernel and aril as affected by drying

PHYSICO-TEXTURAL AND NUTRITIONAL PROPERTIES OF POMEGRANATE KERNEL AND ARIL AS AFFECTED BY DRYING

Abstract

In a quest to explore the value adding potential of pomegranate kernels and arils of three commercially grown pomegranate cultivars (Wonderful, Acco and Herskovitz), this study investigated an array of physico-textural and nutritional properties of pomegranate arils and kernels before and after drying. Drying kinetics of the arils and kernels were also studied. All investigated physical properties of the kernels decreased after drying except for kernel index and shape index which increased from 10.83 – 15.19% to 22.13 – 24.60% and 2.16 – 2.34 to 2.22 – 2.33, respectively. The compressibility properties of kernels of 'Wonderful' and 'Herskovitz' also increased after drying. On the contrary, the hardness, toughness and bioyield of kernels of 'Acco' decreased from 182.00 to 156.04 N, 130.75 to 95.33 N mm and 26.43 to 22.82 N, respectively, after drying. Among the fresh kernels, cv. Acco was the hardest, although dried kernels of 'Wonderful' and 'Herskovitz' were harder than those of 'Acco'. Drying kinetics revealed that pomegranate kernels dried faster than the arils and drying beyond 12 h (for kernels) and 24 h (for arils) influenced the physical and textural properties of both arils and kernels. According to the proximate compositions, 'Acco' kernels contained the highest yield of oil (27.39%), proteins (18.73%), energy (1655.60 kJ/100 g), moisture (0.24%), ash (3.55%) and dietary minerals. However, 'Wonderful' and 'Herskovitz' had the highest contents of carbohydrate (30.65%) and dietary fibre (36.48%), respectively. Overall, the mineral compositions in pomegranate kernels were in the order of Nitrogen > Potassium > Phosphorus > Magnesium > Calcium > Sodium > Iron > Zinc > Copper > Manganese > Boron and these were within the recommended daily allowance ranges proposed by the European Union and United States of America. This suggests that pomegranate kernels could contribute substantially to human dietary nutrition, hence the need to explore their utilisation in food systems.

Keywords: Dietary fibre, Hardness, Mineral analysis, Proximate composition, Value-addition

1. Introduction

Pomegranate fruit is an ancient fruit with several therapeutic and nutritional properties. The fruit has three major parts: the kernels or seeds, the juice and the peels. The kernel and juice are developed in a sac-like structure known as aril. Depending on the cultivar, aril constitutes between 50% and 70% of pomegranate fruit weight whilst the kernel weight corresponds to 15% of a whole aril (Eikani *et al.*, 2012). Processing of pomegranate arils yields juice but also generates pomegranate marc, a co-product made of kernels and aril membranes. Practically, one ton of South African grown pomegranate fruit yields approximately 35% juice and generates about 669 kg of pomegranate waste (marc) (Fawole & Opara, 2015). Uses of pomegranate marc are scarce and their disposal often presents an environmental problem.

However, pomegranate kernels are mainly composed of fibre and oil (Lansky & Newman 2007; Hernández *et al.,* 2011; Eikani *et al.*, 2012; Khoddami *et al.*, 2014). The oil is a promising source of unsaturated fatty acids with over 60% punicic acid content (Aslam *et al.*, 2006; Fadavi *et al.*, 2006; Seeram *et al.*, 2006; Lansky & Newman, 2007; Jing *et al.,* 2012; Viladomiu *et al.*, 2013). Furthermore, other pomegranate plant parts including the kernels have been reported useful to improve beauty and fertility and enhance the efficacy of other disease treatment (Seeram *et al.*, 2006; Ajmal *et al.*, 2014). According to De *et al*. (1999), pomegranate kernels extract could potentially inhibit the growth of *Bacillus subtilis*, *Escherichia coli* and *Saccharomyces cerevisiae*. This antimicrobial activity of the kernels was attributed to presence of punicic acid (De *et al*., 1999). Pomegranate kernels are also effective in neutralising free radicals (Wang *et al.,* 2004; Seeram *et al.,* 2006). Beyond this, pomegranate kernels are used as a raw material in formulating medicinal products (Shafaei *et al.*, 2016).

In addition to their biological properties, the kernels are considered as a rich source of sugar, pectin, fibre, vitamins, mineral elements and polyunsaturated fatty acids (Morton, 1987; Al-Maiman & Ahmad, 2002; Dalimov *et al.*, 2003; Syed *et al*., 2007; Teixeira *et al.*, 2013; Hassan *et al.*, 2014; Khoddami *et al.*, 2014). However, pomegranate kernels are unique and are not like the other fruit kernels. The hardness of pomegranate arils and kernels is of great economic relevance thus the textural properties and moisture migration kinetics need to be understood and prioritised to facilitate processing (Shang-yin *et al*., 2015). In addition, better understanding of their physical attributes would minimize losses, ensure energy efficiency in maintaining industrial high throughput and offer many merits when designing processing and handling equipment (Stroshine, 1998; Sirisomboon *et al.*, 2007; Athmaselvi *et al.*, 2014). Furthermore, since nutrient imbalances in food may aggravate disorders physiologically, the proximate and elemental composition of the kernels may promote their use as dietary supplements in balancing the nutrients of some foods. These may also encourage the use of the kernels as an integral part of functional foods (Crisosto & Costa, 2008; Machado *et al.*, 2015).

From potential value-addition viewpoint, pomegranate kernels could be used to generate bioactive phytochemicals and chemically-rich oil that may be of great interest to food and nutraceutical industries. The primary aim of this study was to add value to pomegranate fruit by investigating the proximate and elemental compositions of the kernels and the physico-textural and processing dependent physico-textural properties of both the arils and kernels of three commercially grown South African pomegranate cultivars (‘Wonderful’, ‘Acco’ and ‘Herskovitz’). This will inform not only cultivar differences for suitability of the fruit kernels as a source of raw material but will also establish processing characteristics of the kernels (for oil extraction) and arils (as in the case of dried shelf-stable aril).

2. Materials and methods

2.1. Kernel preparation

Pomegranate arils were manually separated from Wonderful, Acco and Herskovitz fruit cultivars. The kernels were separated from pomegranate arils using a cheese cloth. Extracted kernels were thoroughly washed in distilled water to remove residual aril sacs, and dried at 60°C in an oven (PROLAB, South Africa) until there was no change in weight. A portion of the dried kernels was used for the physical and textural properties whereas the remaining fraction was grounded into a fine powder using an IKA miller, Model A11B (Germany) and examined for nutritional and elemental compositions (Appendix: Chapter 4, Fig. 1.).

2.2. Physical properties

2.2.1. Weight

Total kernel weight per fruit was measured in 10 replicates using an electronic balance with an accuracy of ± 0.01 g. Weight of individual pomegranate kernels was determined by weighing randomly selected 50 individual kernels (Fawole & Opara, 2013b).

2.2.2. Lineal dimensions and derivatives

The dimension along and perpendicular to the polar axis of both fresh and dried kernel, which represents the length (L) and diameter (D) of the fruit kernels, were measured using a digital vernier calliper (Mitutoyo, Japan) with an accuracy of ± 0.01 mm. Derivatives such as shape index (SI), aspect ratio (A_R), geometric mean diameter (*Dg*), sphericity index (φ), surface area (S_F), volume of oblate spheroid (VSP), and kernel index (KI) were calculated using equations 1 – 7. All findings were presented as mean ± S.E. ($n = 50$). Kernel density (*d*) was determined in five replicates using the toluene displacement technique (equation 8).

$$\text{Shape index, SI} = \frac{L}{D} \tag{1}$$

$$\text{Aspect ratio, } A_R = \frac{D}{L} \tag{2}$$

$$\text{Geometric mean diameter, Dg (mm)} = (L \times D^2)^{1/3} \tag{3}$$

$$\text{Sphericity, } \varphi = \frac{Dg}{L} \tag{4}$$

$$\text{Surface area, } S_F \text{ (cm}^2\text{)} = \pi \times Dg^2 \tag{5}$$

$$\text{Volume of oblate spheroid, VSP (cm}^3\text{)} = \frac{\pi}{6} \times L \times D^2 \tag{6}$$

$$\text{Kernel index, KI (\%)} = \frac{Wk}{Wa} \times 100 \tag{7}$$

$$\text{Density, } d \text{ (g cm}^{-3}\text{)} = \frac{w}{\gamma} \tag{8}$$

Where w is weight, γ is displaced kernel volume, Wk is weight of individual kernel, and Wa is weight of individual aril (Mohsenin, 1970; Martínez *et al.*, 2006; Al-Yahyai *et al.*, 2009; Fawole & Opara, 2013b).

2.2.3. Water activity

The water activity of fresh and dried kernels, conditioned kernels and kernel powder was measured in three replicates at 25°C with the aid of LabMaster-a_w Analyser, Model CH-8853 (Novasina AG, Switzerland).

2.3. Textural properties

The textural properties of fresh and dried kernels were analysed by a Stable Micro System Texture Analyzer, Model TA-XT Plus (UK), with a 35 mm in diameter cylindrical compression probe of 962.11 mm^2 contact area. The operating conditions used were; 1.0 mm/s pre-test speed, 1.0 mm/s probe test speed, 10.0 mm/s post-test speed, 10.0 mm compression distance and 1.0 N compression force. Test was carried out on each randomly selected kernel on a flat steel platform. Bioyield force (N) was characterized as the first fracture; Young's or elastic modulus (N/mm) defined as compression before permanent deformation; Hardness (N) described as the maximum force required for complete deformation; and Toughness (N mm) defined as the total energy required to compress but not break the kernel (Appendix: Chapter 4, Fig. 2) (Al-Said *et al.*, 2009; Bchir *et al.*, 2012; Fawole & Opara, 2013b; Arendse, 2014). All data were therefore presented as mean ± S.E. ($n = 50$).

2.4. Drying dependent properties of arils and conditioned kernels

Prior to the main analysis, a preliminary test was conducted to know the maximum time necessary for the kernels to be saturated with distilled water. Following this, 10 g of the kernels was soaked in distilled water and their weight determined at regular intervals until no change in weight was recorded at the 120th min. As a result, the kernels were immersed in distilled water for 120 min after which water activity and textural properties were evaluated. Subsequently, conditioned kernels (5 g) and arils (20 g) were weighed into petri dishes and kept at 60°C in an oven, with a 1.0 m/s air velocity. Drying kinetics were determined at 60 min/14 h (conditioned kernels) and 60 min/24 h (arils). Physico-textural properties of arils and conditioned kernels were investigated at intervals of 12 h/3 d (conditioned kernels) and 24 h/6 d (arils). All data were presented as mean ± S.E ($n = 3$ (drying kinetics) and $n = 20$ (physico-textural properties)).

2.5. Proximate analysis

2.5.1. Moisture content

The moisture content of pomegranate kernels was evaluated based on AOAC 930.15 (AOAC, 2012) with slight modifications. Ten grams of the kernels put in a clean, dry petri dish was placed in an oven operated at 70°C with a 1.0 m/s air velocity. At regular intervals of 24 h, the test sample was reweighed until there was no change in weight. Moisture content, dry basis (db) and wet basis (wb) were calculated using equation 9 and 10, respectively.

$$\text{Moisture content (\%wb)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \qquad (9)$$

$$\text{Moisture content (\%db)} = \frac{\text{Moisture content (\%wb)}}{100 - \text{Moisture content (\%wb)}} \times 100 \qquad (10)$$

2.5.2. Ash content

According to AOAC 942.05 (AOAC, 2012), finely powdered pomegranate kernels (0.5 g) was put in a pre-weighed, covered crucible and incinerated at 550°C for 13 h in a LABTECH Programmable Digital PID Control Muffle Furnace, Model LEF–115P–1 (Korea). The covered crucible containing ash residues was later cooled in a desiccator and finally reweighed to calculate the percentage ash using equation 11. The experimental data were finally expressed as mean ± S.E ($n = 3$).

$$\text{Ash (\%)} = \frac{\text{Weight of ash}}{\text{Weight of kernel powder}} \times 100 \qquad (11)$$

2.5.3. Fat content

Pomegranate kernel oil (PKO) extraction was carried out in a stepwise extraction process at 40°C for 40 min using *n*-hexane coupled with a MRC ultrasonic bath (Model DC 400H, Haifa, Israel). In brief, 20 g of finely grounded kernel powder was extracted three times with a 200 mL *n*-hexane at a time until a total of 600 mL *n*-hexane was used up. A flowchart of the stepwise extraction process is presented in Appendix: Chapter 5, Fig. 1. The extraction process was trailed by suction filtration to remove kernel powder residues and then the filtrate air dried in a fume hood to recover PKO. The yield of recovered PKO was finally deduced and expressed as mean ± S.E ($n = 3$) using equation 12.

$$\text{Fat (\%)} = \frac{\text{Weight of oil}}{\text{Weight of kernel powder}} \times 100 \qquad (12)$$

2.5.4. Protein content

The Kjeldahl method of AOAC 988.05 (AOAC, 2012) was modified to estimate the protein content of pomegranate kernels. One gram of powdered kernels was mixed with one Kjeltab and 18 mL concentrated H_2SO_4 in a digestion flask. Digestion at 420°C for 60 min was carried out in a VELP Fully Automatic Digestion Unit, Model DKL8 (Europe). The digested sample was allowed to cool before adding 45 mL distilled water and the resulting mixture was distilled for 4 min with 80 mL of 32% NaOH solution. The distillate captured in a 250 mL Erlenmeyer flask that contained a pink solution comprising 40 mL boric acid and 5 drops of an indicator solution (made of 100 mL of 0.1 g bromocresol green and 0.07 g methyl red) resulted in a green colour solution. The green colour solution was then titrated against 0.1 M H_2SO_4 until a pink colour endpoint was reached. Positive control was prepared using 0.100 – 0.105 g glycine whereas blank contained neither glycine nor test sample. Protein content was estimated based on equation 13. All results were presented as mean ± S.E (*n* = 3).

$$\text{Protein (\%)} = \frac{0.28 \times (\text{H2SO4 titre} - \text{Blank titre})}{\text{Weight of powdered kernel}} \times \frac{100}{\text{Nitrogen (\%) in protein}} \qquad (13)$$

2.5.5. Dietary fibre content

Dietary fibre content was measured according to AOAC 993.21 (AOAC, 2005). In duplicates, powdered kernels (0.5 g) was mixed with 25 mL distilled water in 250 mL Erlenmeyer flasks and the mixture gently stirred until test portions were completely wet. The flasks were then covered with aluminium foil and allowed to stand undisturbed for 90 min in a 37°C water bath (Model 132A, Scientific Engineering (Pty) Ltd, South Africa) followed by the addition of 100 mL of 95% ethanol. The mixture was then kept at room temperature (25°C) for 60 min. Following that, the residue from the mixture was collected under vacuum in pre-weighed crucibles containing filter aid. The collected residue was sequentially washed with 78% ethanol (2 × 20 mL), 95% ethanol (2 × 10 mL) and acetone (1 × 10 mL). This was followed by drying crucibles containing residue at 105°C for 2 h and subsequently, cooling in a desiccator for additional 2 h. The weight of the crucibles containing the residue was measured and ash and crude proteins analysed. Ash content from one duplicates was determined by incinerating the residue in a muffle furnace operated at 525°C for 5 h followed by a 2 h cooling in a desiccator and percentage ash estimated according to AOAC 942.05 (AOAC, 2012). Crude protein from the remaining residue was determined by Kjeldahl method of AOAC 988.05 (AOAC, 2012). Total dietary fibre (TDF) was evaluated according to equation 14. All data were expressed as mean ± S.E (*n* = 3).

$$\text{TDF (\%)} = 100 \times \frac{\text{Weight (residue)} - \frac{\text{Protein (\%) in residue} + \text{Ash (\%) in residue}}{100} \times \text{Weight (residue)}}{\text{Weight of powdered kernel}} \qquad (14)$$

2.5.6. Carbohydrate content

The carbohydrate content of pomegranate kernels was deduced by equation 15.

$$\text{Carbohydrate (\%)} = 100 - (\text{\% Moisture} + \text{\% Ash} + \text{\% TDF} + \text{\% Protein} + \text{\% Fat}) \qquad (15)$$

2.4.7. Energy content

Energy (E) content of pomegranate kernels was calculated as illustrated in equations 16 – 19 (Whitney & Rolfes, 2005).

$$\text{E in Fat (kJ/100 g kernels)} = \text{\% Fat} \times 37 \tag{16}$$

$$\text{E in Protein (kJ/100 g kernels)} = \text{\% Protein} \times 17 \tag{17}$$

$$\text{E in Carbohydrate (kJ/100 g kernels)} = \text{\% Carbohydrate} \times 17 \tag{18}$$

$$\text{Total E (kJ/100 g kernels)} = \text{E in Fat} + \text{E in Protein} + \text{E in Carbohydrate} \tag{19}$$

2.6. Mineral elements profile

The mineral content of pomegranate kernels was analysed and profiled at Bemlab Analytical Laboratory, Strand, South Africa, accredited by the South African National Accreditation System (SANAS) in conformation with recognised International Standards. Powdered test sample (5.0 g) was ashed at 480ºC in a muffle furnace and then mixed with 100 mL of 10 M HCl prepared in distilled water in a 1:1 ratio. The mixture was filtered through a filter paper and the filtrate analysed for macro elements; phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na), as well as trace elements; manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) and boron (B), using an inductively coupled plasma-optical emission spectrometry (ICP-OES) (Varian-Vista; Australia) calibrated with different concentrations of standard solutions of the minerals. The operating parameters for the ICP-OES included radio frequency (RF) power of 0.7 – 1.5 kW (1.2 – 1.3 kW for axial), plasma gas flow rate (Ar) of 10.5 – 15.0 L/min (radial) and 15.0 L/min (axial), auxiliary gas flow rate (Ar) of 1.5 L/min, viewing height of 5 – 12 mm, copy and reading time of 1 – 5 s (max 60 s), and copy time of 3 s (max 100 s). Total nitrogen (N) was however determined by a total combustion method in a Leco N-analyser (Campbell & Plank, 1998; Miller, 1998; Fawole & Opara, 2012). All results were therefore presented as mean ± S.E ($n = 3$).

3. Statistical analysis

Analysis of Variance (ANOVA) was performed using Statistica 64, version 13. Whereas one-way ANOVA compared the mean differences between cultivar and kernel or aril property, two-way ANOVA helped to understand the interaction between two independent variables (cultivar and processing) on a dependent variable (kernel or aril property). Also, the observed, weighted means were separated using Duncan Multiple Range Test (DMRT) with a statistical significance of 5% confidence level. DMRT allowed for the classification (significant or non-significant) of differences among means of kernel or aril property. Graphical presentations were presented using GraphPad Prism, version 5.00 (GraphPad Software, San Diego, USA) and Microsoft Excel (Microsoft Office Professional Plus, Microsoft Corp., 2016). Principal Component Analysis (PCA) was carried out using XLSTAT, version 2012.04.1 (Addinsoft, France).

4. Results and discussion

4.1. Physical properties

As presented in Table 1, pomegranate kernel constitutes an integral factor that may be considered when packaging and modelling plant yield and load for transfer and storage (Arshad *et al.*, 2014). There were significant differences in kernel weight per fruit between fresh and dried kernels for each studied cultivar with no cultivar differences ($p = 0.1918$). Factorial analysis indicated drying ($p < 0.0001$) as the factor that influenced weight of kernels per fruit whereas both cultivar ($p < 0.0001$) and drying ($p < 0.0001$) influenced the weight of the individual kernels. On the contrary, the weight of a dried kernel differed substantially with ‘Acco’ and ‘Wonderful’ dried kernel being lightest and heaviest, respectively (Table1).

Furthermore, significant differences in lineal dimensions and derivatives of pomegranate kernel were observed between fresh and dried kernels and among the pomegranate cultivars. Both fresh and dried kernels of cv. Acco had the least volume and the highest density. Variations in these parameters are attributed to differences in cultivar and drying of pomegranate kernels (Table1). Similarly, shape index (SI) and aspect ratio (A_R) of the kernels were also driven by differences in cultivars although SI (2.16 – 2.34) for fresh kernels in this study were lower than that (3.13) reported for Iranian cultivars (Sarkhosh *et al.*, 2009). This may be possibly due to variations in cultivar selection and growing region. Furthermore, length, diameter, geometric mean diameter, surface area, sphericity of kernel, as well as kernel index reduced after drying. Again, with the exception of kernel length, reduction in these parameters was cultivar dependent (Table 1). The length of fresh kernels (7.00 – 7.13 mm) for the studied cultivars were in the ranges reported for fresh kernels of pomegranate cultivars grown in Iran (6.9 – 7.6 mm) (Sarkhosh *et al.*, 2009; Riyahi *et al.*, 2011), Morocco (6.7 – 7.3 mm) (Martínez *et al.*, 2012) and South Africa (7.0 – 7.5 mm) (Fawole & Opara, 2013b). However, while diameter of fresh kernels (3.01 – 3.34 mm) for the investigated cultivars were similar to those (3.0 – 3.3 mm) reported by Fawole & Opara (2013b), the diameter of kernels examined in the present study was bigger than those reported for Iran (2.4 – 2.8 mm) (Sarkhosh *et al.*, 2009; Riyahi *et al.*, 2011) and Morocco (2.0 – 2.6 mm) (Martínez *et al.*, 2012).

The kernel index (KI), which quantifies the woody portion of pomegranate kernels (Martínez *et al.*, 2006), was two folds lower in fresh kernels compared to dried kernels (Table 1). In terms of cultivar differences, KI for cv. Herskovitz differed significantly within fresh and dried kernel groups. This implies that the kernels of ‘Herskovitz’ may be a rich source of fibre. KI range of fresh kernels (10.83 – 15.19) were higher than those reported by Fawole & Opara (2013b) (6.1 – 14.8), Hasnaoui *et al.* (2011) (3.35 – 6.50) and Martínez *et al.* (2006) (7.80 – 9.68). In view of these, in addition to kernel crude fibre and hardness, KI could serve as a relevant attribute for any prospective selection of pomegranate fruit for processing (Hasnaoui *et al.*, 2011). Furthermore, the average count of kernels per fruit was in order of ‘Herskovitz’ > ‘Acco’ > ‘Wonderful’ (Table 1).

4.1.3. Water activity

The water activity of a fruit is an indispensable factor in its processing and nutrition. Knowledge of water activity can be used to assess susceptibility of fruit to spoilage by microorganisms in collaboration with its pH, predict moisture migration kinetics and undesirable characteristics that may influence organoleptic properties of fruit, and examine the rate of important enzymatic and non-enzymatic reactions including Maillard reactions that occur in fruit during processing and storage (Velíšek, 2014). As reported in Table 1, the water activity of fresh and dried kernels varied significantly and ranged between 0.97 – 0.98 and 0.29 – 0.33, respectively. Whilst dried kernels may be grouped with biscuits, dried milk and instant coffee, fresh kernels may be categorised with eggs, bread, fruits and vegetables (Velíšek, 2014). This suggests that dried kernels may be highly resistant to any form of microbial spoilage whereas fresh kernels are likely vulnerable to microbial infestation, hence having shorter shelf life.

4.2. Textural properties

Textural properties of pomegranate kernels varied significantly ($p < 0.05$) between fresh and dried kernels and among the cultivars (Table 2). Among fresh kernels, cv. Acco was the hardest. Kernel hardness constitutes a key sensory attribute for pomegranate fruit intended for fresh consumption

(Szychowski *et al.,* 2015). Kernel hardness increased after drying for 'Wonderful' and 'Herskovitz' whereas a decrease was observed for 'Acco', albeit dried kernels of 'Wonderful' and 'Herskovitz' were harder than kernels of 'Acco' (Table 2). Kernel toughness followed a similar trend as kernel hardness. There were significant interaction effects ($p < 0.0001$) between cultivar and drying for both hardness and toughness (Table 2), which made it inconclusive on factors that influenced kernel hardness and toughness. Kernel hardness is also a vital trait used for classifying pomegranate fruit cultivars and as an implication, influences prospect of consumer preference (Al-Said *et al.,* 2009; Hasnaoui *et al.*, 2011).

In comparison, hardness and toughness of fresh kernel in this study were higher than those reported for fresh kernels of fruit cultivars harvested in Oman (hardness = 26.62 – 44.73 N; toughness = 5.86 – 10.66 N mm) (Al-Said *et al.,* 2009) and South Africa (hardness = 66.6 – 103.6 N; toughness = 35.2 – 65.6 N mm) (Fawole & Opara, 2013b). The patterns in hardness and toughness were reflected in bioyield force, which was mainly cultivar dependent ($p < 0.0001$). In particular, Acco cultivar had the lowest bioyield force while there were no significant differences between 'Wonderful' and 'Herskovitz' (Table 2). Unlike bioyield, elastic modulus increased substantially after drying, suggesting a greater tendency of dried kernels to recover from deformation. The reduction in hardness, toughness and bioyield of kernels of 'Acco' after drying could be explained by its relatively high oil yield and low fibre and carbohydrate contents (Table 4).

4.3. Drying dependent properties of arils and conditioned kernels

4.3.1. Drying kinetics of arils and conditioned kernels

As the most diverse unit operations, dehydration of fruit remains the oldest technique in fruit processing. Fruit dehydration offers substantial benefits in preservation, reduction in size and weight, as well as cost of transportation and storage (Zielinska & Michalska, 2016). As governed by internal moisture transfer, the moisture content, moisture ratio and drying rate of the arils (Fig. 1) and conditioned kernels (Fig. 2) decreased exponentially as drying time elapsed and stabilised after the 13th h (arils) and 5th h (conditioned kernels). The differences observed in the early hours of drying can therefore be attributed to the differences in the initial moisture content of the arils (Fig. 1) and conditioned kernels (Fig. 2). Interestingly, the kernels of 'Acco', despite being smallest in lineal dimensions (Table 1), exhibited the greatest water absorbing capacity in the distilled water conditioning process. This was subsequently followed by kernels of cv. Herskovitz and Wonderful. From energy conservation perspective, this study provides important reasons for optimizing drying time, temperature and processing conditions in the drying of pomegranate arils and kernels.

4.3.2. Drying dependent physical properties of arils

Mostly, there were no significant differences in the lineal dimensions and derivatives of dried pomegranate arils. However, as expected, significant variations between fresh and dried arils were observed in the first 24 h of drying. Factorial analysis further showed that the lineal dimensions and derivatives of the arils were all dependent on the interactions between cultivar and drying (Table 3).

4.3.3. Drying dependent water activity of arils and conditioned kernels

Water activity declined significantly in the first 24 h (arils) (Fig. 3) and 12 h (conditioned kernels) (Fig. 4) drying period and remained stable afterwards. It is however inconclusive as to which factor contributed to the variation in water activity due to significant interaction ($p < 0.0001$) between cultivar and drying (Appendix: Chapter 4, Table 1). From energy conservation perspective, the knowledge of drying kinetics and drying dependent water activity may be useful for optimizing processing conditions, especially for drying of pomegranate kernels in the industries.

4.3.4. Drying dependent textural properties of arils and conditioned kernels

The investigated textural properties of dried pomegranate arils were significantly ($p < 0.05$) different from the fresh ones (Fig. 5). A similar pattern was also observed for conditioned kernels (Fig. 6). Overall, as expected, fresh arils and conditioned kernels were the softest. This can be explained by the presence of juice in the aril and the absorbed water by the conditioned kernels. Hardness and toughness followed the same pattern for all the cultivars. A big increase in both parameters was observed in the arils (Fig. 5), as opposed to a slight increase for the conditioned kernels (Fig. 6), after 12 h and 24 h drying period, respectively. These were followed by insignificant changes as drying progressed. While there were no significant differences between cvs. Wonderful and Herskovitz, textural properties for conditioned kernels of ‘Acco’ were significantly lower than the other investigated cultivars (Fig. 6). A similar trend was also observed for the arils (Fig. 5). The bioyield force and elastic modulus of both arils and conditioned kernels followed the same pattern as reported for hardness and toughness of conditioned kernels.

According to factorial analysis, changes in hardness and elastic modulus of conditioned kernels were significantly influenced by the combined effects of cultivar ($p < 0.0001$) and drying time ($p <$

0.0001), whereas toughness and bioyield were only influenced by differences in cultivar. However, it was inconclusive for the arils as all the investigated textural properties were dependent on the interaction between cultivar and drying time (Appendix: Chapter 4, Table 1). This study showed that dried arils and kernels of pomegranate fruit had a greater tendency to recover from deformation (elastic modulus) than fresh arils and kernels. In addition, dried pomegranate arils and kernels would require significantly higher force for crushing as evidently manifested in their hardness, toughness and bioyield. Extending the drying time beyond 24 h (arils) and 12 h (kernels) had an insignificant influence on their textural properties. This knowledge could guide processors in the design of efficient equipment or device with the required mechanical power to process pomegranate kernels (for oil extraction) and arils (as in the case of dried shelf-stable aril).

4.4. Nutritional properties

4.4.1. Proximate composition

Nutritional analysis of pomegranate kernels is essential to promote its utilisation in food systems, for formulation and fortification of new or existing products. Moisture content in kernels of the investigated pomegranate cultivars ranged between 18.07 and 19.17% dry basis (Table 4). This range was higher than those reported for cultivars grown in Iran (13.2%) (Khoddami *et al.*, 2014) and Egypt (8.60%) (El-Nemr *et al.*, 1990). However, the presently reported moisture contents were lower than those published for kernels of pomegranate cultivars grown in Saudi Arabia (57.83 – 80.66%) and Nigeria (48.40%) (Al-Maiman & Ahmad, 2002; Dangoggo *et al.*, 2012). Furthermore, dried kernel powder had water activity values ranging between 0.50 – 0.52, suggesting less susceptibility to microbial spoilage hence longer shelf stability (Table 4). Ash content in kernels of the investigated cultivars ranged between 1.92 – 3.55%, with significantly higher contents in Acco and Herskovitz cultivars (Table 4). High ash content signifies the presence of high levels of dietary minerals (Fig. 7 and Fig. 8). In comparison with other reports, the ash contents of this study were higher than those reported for cultivars grown in Saudi Arabia (0.43 – 1.53%), Nigeria (2.00%) (Al-Maiman & Ahmad, 2002; Dangoggo *et al.*, 2012), Egypt (2.00%) (El-Nemr *et al.*, 1990) and Iran (1.46%) (Khoddami *et al.*, 2014).

Fat content of pomegranate kernel ranged between 17.95 – 27.39%, with no significant differences among the cultivars (Table 4). The remarkably high levels of oil in the investigated pomegranate kernel underscore its importance as a source of bioactive specialty oil. In addition, it suggests that the kernels, regardless of cultivar, could be exploited for multiple applications in food, cosmeceutical and nutraceutical industries. Moreover, there were appreciable amounts of dietary fibre in pomegranate kernel, ranging between 31.05 – 36.48%, with no significant differences among the investigated cultivars (Table 4). This suggests that the fibre content of the kernels, regardless of cultivar, could enhance faecal bulkiness and provide bowel function after consumption. The total energy yield of pomegranate kernels ranged between 1414.68 – 1655.60 kJ/100 g with 664.28 – 1013.60 kJ/100 g, 256.68 – 318.45 kJ/100 g, and 323.55 – 521.02 kJ/100 g corresponding to energy in fat, protein and carbohydrate quantified in the kernels (Table 4). This indicates that pomegranate kernels could be a great source for daily energy requirements, regardless of cultivar.

4.4.2. Mineral elements profile

4.4.2.1. Macro minerals

A chemical make-up of food can be viewed in either its individual principal component or its elemental composition (Velíšek, 2014). Assessment of elemental composition of pomegranate kernel showed that macro elements (except nitrogen) differed significantly ($p < 0.05$) among the cultivars. The highest amounts of macro elements were recorded for cv. Acco (Fig. 7). Overall, the abundance of macro elements was in the order of Nitrogen > Potassium > Phosphorus > Magnesium > Calcium > Sodium. In comparison with other pomegranate fruit parts, the present research data indicates that pomegranate kernels, regardless of cultivar, are a rich source of macro elements (Fawole & Opara, 2012; Fawole & Opara, 2013a). This implies that pomegranate kernel could contribute substantially to the human dietary nutrition.

4.4.2.2. Micro minerals

The composition in micro elements in the fruit kernels of the investigated pomegranate cultivars is presented in Fig. 8. Similar to macro elements, the kernels of cv. Acco contained the largest quantities of micro elements. Micro elements in pomegranate kernels were in the order of Iron > Zinc > Copper > Manganese > Boron. Again, pomegranate kernels, according to the present research data, contained more micro elements than other pomegranate fruit parts (Fawole & Opara, 2012; Fawole & Opara, 2013a). In comparison to the Recommended Daily Allowance (RDA) stipulated in the European Union and United States of America, the study indicates that the investigated pomegranate kernels could be explored as an essential source of dietary elements that can be added to food either by restitution or fortification (Velíšek, 2014).

4.5. Principal Component Analysis result

To elucidate the uniqueness of the kernels of 'Wonderful', 'Acco' and 'Herskovitz' in the ease of processing and nutrition, the data set of the measured properties were subjected to Principal Component Analysis (PCA) (Fig. 9). Factors 1 and 2 (F1 and F2) accounted for 67.72% and 32.28% variations in the investigated cultivars, respectively (Appendix: Chapter 4 Table 2). Overall, 'Acco' is characterised by hardness and shape index of fresh kernels, ash, proteins, fat, total energy and dietary minerals. 'Wonderful' is mostly associated with bigger physical dimensions and textural properties. 'Herskovitz', on the other hand, is characterised by higher dietary fibre, kernel index and water activity of fresh and powder kernels. This therefore implies that the kernels of all the investigated cultivars possess quality attributes suitable for processing and are therefore desirable in the food industry.

5. Conclusions

Both drying and cultivar had significant influence on the physical and textural properties of pomegranate kernels. Except for kernel index and shape index that increased after drying, all other investigated physical property of pomegranate kernels decreased. In contrast, all textural properties of kernels of 'Wonderful' and 'Herskovitz' increased after drying. However, the kernels of 'Acco' behaved differently as they recorded a remarkable reduction in hardness, toughness and bioyield after drying. Comparatively, pomegranate kernels dried faster than the arils. Extending drying beyond 12 h (kernels) and 24 h (arils) had an insignificant contribution to the physical and textural properties of pomegranate arils and kernels. Furthermore, from potential value-addition viewpoint, the kernels of Acco cultivar may be preferred as their proximate and elemental compositions revealed a greater amount of proteins, oil and energy, as well as dietary minerals in 'Acco' as compared to 'Wonderful' and 'Herskovitz'. Nonetheless, the nutritional properties of the kernels suggest that pomegranate kernels, regardless of cultivar, could contribute substantially to human dietary nutrition hence the need to explore their utilisation in food systems.

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Table 1: Physical properties of fresh and dried kernels of three pomegranate fruit cultivars harvested in South Africa

	Cultivar								
	Wonderful		Acco		Herskovitz		Cultivar	Drying	Cultivar × Drying
Property	Fresh	Dried	Fresh	Dried	Fresh	Dried	**(A)**	**(B)**	**(A × B)**
Weight of kernels per fruit (g)	31.79±2.66^{a}	13.10±1.23^{b}	31.09±1.98^{a}	10.34±0.65^{b}	33.54±1.71^{a}	13.98±0.76^{b}	0.1918	<0.0001	0.8221
Kernel weight (g)	0.04±0.00^{a}	0.02±0.00^{c}	0.04±0.00^{b}	0.02±0.00^{e}	0.04±0.00^{b}	0.02±0.00^{d}	<0.0001	<0.0001	0.1011
Volume (cm^{3})	0.18±0.02^{a}	0.12±0.01^{bd}	0.14±0.02^{b}	0.10±0.01^{dc}	0.13±0.01^{bc}	0.09±0.00^{d}	<0.0001	<0.0001	0.7029
Density (g/cm^{3})	0.26±0.03^{ab}	0.16±0.01^{c}	0.33±0.05^{a}	0.18±0.01^{cb}	0.33±0.03^{a}	0.23±0.02^{cb}	0.0927	<0.0001	0.5337
Length (mm)	7.11±0.09^{a}	6.89±0.07^{ab}	7.00±0.07^{a}	6.76±0.06^{b}	7.13±0.07^{a}	6.96±0.09^{ab}	0.0794	<0.0001	0.8997
Diameter (mm)	3.34±0.06^{a}	3.13±0.04^{bc}	3.01±0.04^{cd}	2.94±0.04^{d}	3.22±0.04^{b}	3.04±0.04^{cd}	<0.0001	<0.0001	0.2858
Shape index	2.16±0.05^{b}	2.22±0.04^{ab}	2.34±0.04^{a}	2.33±0.05^{a}	2.23±0.04^{ab}	2.31±0.05^{a}	<0.0001	0.2427	0.5644
Aspect ratio	0.47±0.01^{a}	0.46±0.01^{ab}	0.43±0.01^{b}	0.44±0.01^{b}	0.45±0.01^{ab}	0.44±0.01^{b}	<0.0001	0.2555	0.4197
Geo mean D (mm)	4.22±0.05^{a}	4.01±0.04^{b}	3.93±0.03^{b}	3.82±0.04^{c}	4.13±0.03^{a}	3.94±0.04^{b}	<0.0001	<0.0001	0.3976
Sphericity index	0.60±0.01^{a}	0.58±0.01^{ab}	0.56±0.01^{b}	0.57±0.01^{b}	0.58±0.01^{ab}	0.57±0.01^{b}	<0.0001	0.2656	0.4480
Surface area (cm^{2})	0.56±0.01^{a}	0.51±0.01^{b}	0.49±0.01^{bc}	0.46±0.01^{c}	0.54±0.01^{a}	0.49±0.01^{b}	<0.0001	<0.0001	0.3235
VSP (cm^{3})	0.04±0.00^{a}	0.04±0.00^{c}	0.03±0.00^{cd}	0.03±0.00^{d}	0.04±0.00^{b}	0.03±0.00^{c}	<0.0001	<0.0001	0.2589
Kernel index (%)	11.28±0.28^{d}	22.13±0.61^{b}	10.83±0.20^{d}	22.32±0.51^{b}	15.19±0.43^{c}	24.60±0.50^{a}	<0.0001	<0.0001	0.0581
Water activity	0.97±0.00^{b}	0.32±0.00^{d}	0.97±0.00^{ab}	0.33±0.00^{c}	0.98±0.00^{a}	0.29±0.00^{e}	<0.0001	<0.0001	<0.0001

Number of kernels per fruit: 614.20±57.68^{a} (‘Wonderful’); 645.50±40.45^{a} (‘Acco’); 742.40±40.39^{a} (‘Herskovitz’).

Values followed by different letters in the same row are significantly different at 5% level by Duncan Multiple Range Test.

Red ink designates a significant level and hence a determining factor.

Geometric mean diameter (Geo mean D). Volume of oblate spheroid (VSP).

Table 2: Textural properties of fresh and dried kernels of three pomegranate fruit cultivars harvested in South Africa

	Cultivar								
	Wonderful		Acco		Herskovitz		Cultivar	Drying	Cultivar × Drying
Property	Fresh	Dried	Fresh	Dried	Fresh	Dried	**(A)**	**(B)**	**(A × B)**
Hardness (N)	166.89 ± 2.67^{c}	199.11 ± 2.63^{a}	182.00 ± 3.82^{b}	156.04 ± 2.08^{d}	153.76 ± 3.53^{d}	203.18 ± 4.49^{a}	<0.0001	<0.0001	<0.0001
Toughness (N mm)	137.71 ± 3.90^{ab}	148.05 ± 3.36^{a}	130.75 ± 3.20^{bc}	95.33 ± 1.75^{d}	121.64 ± 3.98^{c}	147.70 ± 4.78^{a}	<0.0001	0.9123	<0.0001
Bioyield (N)	37.33 ± 1.75^{a}	43.28 ± 3.17^{a}	26.43 ± 2.23^{b}	22.82 ± 1.33^{b}	37.38 ± 2.08^{a}	39.20 ± 2.77^{a}	<0.0001	0.4630	0.1168
Elastic modulus (N/mm)	34.48 ± 1.84^{cd}	53.78 ± 3.05^{a}	29.85 ± 1.70^{d}	40.09 ± 2.33^{bc}	35.75 ± 2.00^{cd}	42.78 ± 2.78^{b}	<0.0001	<0.0001	<0.0001

Values followed by different letters in the same row are significantly different at 5% level by Duncan Multiple Range Test.

Red ink designates a significant level and hence a determining factor.

Table 3: Drying dependent physical properties of arils of three pomegranate fruit cultivars harvested in South Africa

		Cultivar					
Property	Drying (h)	Wonderful	Acco	Herskovitz	Cultivar (**A**)	Drying (**B**)	Cultivar × Drying (**A×B**)
Weight (g)	0	0.36 ± 0.01^{a}	0.34 ± 0.00^{b}	0.23 ± 0.01^{c}	<0.0001	<0.0001	<0.0001
	24	0.07 ± 0.00^{de}	0.06 ± 0.00^{e}	0.06 ± 0.00^{e}			
	48	0.07 ± 0.00^{de}	0.06 ± 0.00^{e}	0.07 ± 0.00^{de}			
	72	0.07 ± 0.00^{de}	0.06 ± 0.00^{e}	0.06 ± 0.00^{e}			
	96	0.06 ± 0.00^{e}	0.06 ± 0.00^{e}	0.06 ± 0.00^{de}			
	120	0.06 ± 0.00^{de}	0.05 ± 0.00^{e}	0.06 ± 0.00^{e}			
	144	0.06 ± 0.00^{de}	0.06 ± 0.00^{e}	0.05 ± 0.00^{e}			
Length (mm)	0	10.37 ± 0.11^{a}	10.29 ± 0.09^{a}	9.17 ± 0.08^{b}	<0.0001	<0.0001	<0.0001
	24	$7.86 \pm 0.16^{d-j}$	8.21 ± 0.18^{cde}	7.45 ± 0.15^{j}			
	48	$8.05 \pm 0.13^{d-i}$	$8.09 \pm 0.16^{c-h}$	$7.80 \pm 0.15^{e-j}$			
	72	$8.14 \pm 0.19^{c-g}$	$8.16 \pm 0.14^{c-g}$	7.66 ± 0.11^{hij}			
	96	$7.89 \pm 0.15^{d-j}$	$8.16 \pm 0.20^{c-g}$	$7.74 \pm 0.17^{f-j}$			
	120	$8.00 \pm 0.14^{d-i}$	8.54 ± 0.14^{c}	7.65 ± 0.12^{hij}			
	144	8.22 ± 0.17^{cde}	8.29 ± 0.13^{cd}	$7.72 \pm 0.13^{g-j}$			
Diameter (mm)	0	7.34 ± 0.10^{a}	7.36 ± 0.09^{a}	6.27 ± 0.09^{b}	<0.0001	<0.0001	<0.0001
	24	4.10 ± 0.16^{ghi}	3.90 ± 0.13^{i}	3.94 ± 0.12^{hi}			
	48	4.57 ± 0.15^{def}	4.11 ± 0.12^{ghi}	4.12 ± 0.12^{ghi}			
	72	$4.26 \pm 0.11^{f-i}$	4.10 ± 0.14^{ghi}	$4.16 \pm 0.13^{f-i}$			
	96	$4.36 \pm 0.15^{d-h}$	$4.15 \pm 0.12^{f-i}$	$4.39 \pm 0.13^{d-g}$			
	120	4.69 ± 0.15^{de}	$4.19 \pm 0.16^{f-i}$	$4.24 \pm 0.14^{f-i}$			
	144	4.76 ± 0.15^{d}	$4.18 \pm 0.13^{f-i}$	$4.27 \pm 0.11^{e-i}$			

For each property, values followed by different letters, regardless of the row and column, are significantly different at 5% level by Duncan Multiple Range Test.

Red ink designates a significant level and hence a determining factor.

Table 3 (continues)

Table 3: Drying dependent physical properties of arils of three pomegranate fruit cultivars harvested in South Africa

		Cultivar					
Property	Drying (h)	Wonderful	Acco	Herskovitz	Cultivar (**A**)	Drying (**B**)	Cultivar × Drying (**A×B**)
Shape index	0	1.42 ± 0.02^{k}	1.41 ± 0.02^{k}	1.47 ± 0.02^{k}	<0.0001	<0.0001	<0.0001
	24	1.96 ± 0.07^{b-k}	2.15 ± 0.09^{a}	1.92 ± 0.06^{b-h}			
	48	1.79 ± 0.06^{f-j}	2.00 ± 0.07^{a-e}	1.91 ± 0.05^{b-h}			
	72	1.93 ± 0.06^{b-g}	2.03 ± 0.07^{abc}	1.88 ± 0.07^{c-i}			
	96	1.85 ± 0.07^{c-i}	2.01 ± 0.09^{a-e}	1.80 ± 0.07^{f-j}			
	120	1.74 ± 0.07^{hij}	2.09 ± 0.08^{ab}	1.84 ± 0.06^{d-i}			
	144	1.76 ± 0.07^{g-j}	2.01 ± 0.06^{a-d}	1.82 ± 0.05^{e-i}			
Aspect ratio	0	0.71 ± 0.01^{a}	0.72 ± 0.01^{a}	0.69 ± 0.01^{ab}	<0.0001	<0.0001	<0.0001
	24	0.52 ± 0.02^{f-k}	0.48 ± 0.02^{k}	0.53 ± 0.02^{e-k}			
	48	0.57 ± 0.02^{d-h}	0.51 ± 0.02^{g-k}	0.53 ± 0.01^{e-k}			
	72	0.53 ± 0.02^{e-k}	0.50 ± 0.02^{ijk}	0.55 ± 0.02^{d-j}			
	96	0.56 ± 0.02^{d-i}	0.52 ± 0.02^{g-k}	0.57 ± 0.02^{d-g}			
	120	0.59 ± 0.02^{cde}	0.49 ± 0.02^{jk}	0.56 ± 0.02^{d-i}			
	144	0.59 ± 0.02^{def}	0.51 ± 0.02^{h-k}	0.56 ± 0.02^{d-i}			
Geometric mean diameter (mm)	0	8.05 ± 0.08^{a}	8.05 ± 0.07^{a}	6.98 ± 0.08^{b}	<0.0001	<0.0001	<0.0001
	24	5.00 ± 0.14^{ghi}	4.90 ± 0.11^{hi}	4.78 ± 0.11^{i}			
	48	5.42 ± 0.13^{def}	5.05 ± 0.11^{ghi}	5.01 ± 0.11^{ghi}			
	72	5.19 ± 0.10^{e-h}	5.06 ± 0.12^{f-i}	5.00 ± 0.10^{ghi}			
	96	5.21 ± 0.12^{e-h}	5.09 ± 0.09^{f-i}	5.19 ± 0.11^{e-h}			
	120	5.49 ± 0.12^{de}	5.20 ± 0.14^{e-h}	5.07 ± 0.12^{f-i}			
	144	5.60 ± 0.12^{cd}	5.16 ± 0.12^{e-h}	5.11 ± 0.09^{f-i}			

For each property, values followed by different letters, regardless of the row and column, are significantly different at 5% level by Duncan Multiple Range Test.

Red ink designates a significant level and hence a determining factor.

Table 3 (continues)

Table 3: Drying dependent physical properties of arils of three pomegranate fruit cultivars harvested in South Africa

Property	Drying (h)	Cultivar			Cultivar (**A**)	Drying (**B**)	Cultivar × Drying (**A×B**)
		Wonderful	Acco	Herskovitz			
Sphericity index	0	0.78 ± 0.01^{a}	0.78 ± 0.01^{a}	0.76 ± 0.01^{ab}	<0.0001	<0.0001	<0.0001
	24	0.64 ± 0.02$^{f\text{-}k}$	0.60 ± 0.02^{k}	0.64 ± 0.01$^{e\text{-}k}$			
	48	0.67 ± 0.01$^{d\text{-}h}$	0.63 ± 0.01$^{h\text{-}k}$	0.64 ± 0.01$^{e\text{-}k}$			
	72	0.64 ± 0.01$^{f\text{-}k}$	0.62 ± 0.01^{ijk}	0.66 ± 0.02$^{d\text{-}j}$			
	96	0.66 ± 0.02$^{d\text{-}i}$	0.63 ± 0.02$^{g\text{-}k}$	0.68 ± 0.02$^{d\text{-}g}$			
	120	0.69 ± 0.02^{cde}	0.61 ± 0.02^{jk}	0.66 ± 0.02$^{d\text{-}i}$			
	144	0.69 ± 0.02$^{c\text{-}f}$	0.62 ± 0.01^{kl}	0.66 ± 0.01$^{d\text{-}i}$			
Surface area (cm^2)	0	2.05 ± 0.04^{a}	2.04 ± 0.04^{a}	1.54 ± 0.03^{b}	<0.0001	<0.0001	<0.0001
	24	0.79 ± 0.05$^{f\text{-}h}$	0.76 ± 0.03^{gh}	0.73 ± 0.03^{h}			
	48	0.93 ± 0.04^{def}	0.81 ± 0.03^{fgh}	0.79 ± 0.04^{fgh}			
	72	0.85 ± 0.03$^{e\text{-}h}$	0.81 ± 0.04^{fgh}	0.79 ± 0.03^{gh}			
	96	0.86 ± 0.04$^{d\text{-}h}$	0.82 ± 0.03$^{e\text{-}h}$	0.85 ± 0.04$^{e\text{-}h}$			
	120	0.95 ± 0.04^{de}	0.86 ± 0.04$^{e\text{-}h}$	0.81 ± 0.04^{fgh}			
	144	0.99 ± 0.04^{cd}	0.84 ± 0.04$^{e\text{-}h}$	0.82 ± 0.03$^{e\text{-}h}$			
Volume of oblate spheroid (cm^3)	0	0.30 ± 0.01^{a}	0.29 ± 0.01^{a}	0.19 ± 0.01^{b}	<0.0001	<0.0001	<0.0001
	24	0.07 ± 0.01^{efg}	0.07 ± 0.00^{fg}	0.06 ± 0.00^{g}			
	48	0.09 ± 0.01^{def}	0.07 ± 0.00^{efg}	0.07 ± 0.01^{efg}			
	72	0.08 ± 0.00$^{d\text{-}g}$	0.07 ± 0.01^{efg}	0.07 ± 0.00^{efg}			
	96	0.08 ± 0.01$^{d\text{-}g}$	0.07 ± 0.00^{efg}	0.08 ± 0.01$^{d\text{-}g}$			
	120	0.09 ± 0.01^{de}	0.08 ± 0.01$^{d\text{-}g}$	0.07 ± 0.01^{efg}			
	144	0.10 ± 0.01^{cd}	0.08 ± 0.01$^{d\text{-}g}$	0.07 ± 0.00^{efg}			

For each property, values followed by different letters, regardless of the row and column, are significantly different at 5% level by Duncan Multiple Range Test.

Red ink designates a significant level and hence a determining factor.

Table 4: Proximate composition of kernels of Wonderful, Acco and Herskovitz pomegranate cultivars

	Cultivar		
Proximate composition (dry basis)	Wonderful	Acco	Herskovitz
Moisture (%)	0.22±0.00^{b}	0.24±0.00^{a}	0.22±0.01^{b}
Ash (%)	1.92±0.18^{b}	3.55±0.07^{a}	2.80±0.34^{a}
Fat (%)	17.95±1.67^{a}	27.39±4.05^{a}	19.30±3.42^{a}
Protein (%)	16.85±0.18^{b}	18.73±0.07^{a}	15.10±0.84^{c}
Dietary fibre (%)	32.41±0.82^{a}	31.05±3.63^{a}	36.48±1.25^{a}
Carbohydrate (%)	30.65±5.91^{a}	19.03±6.19^{b}	26.11±6.51^{ab}
Energy in fat (kJ/100 g)	664.28±61.71^{a}	1013.60±149.68^{a}	714.22±126.69^{a}
Energy in protein (kJ/100 g)	286.48±3.11^{b}	318.45±1.14^{a}	256.68±14.36^{c}
Energy in carbohydrate (kJ/100 g)	521.02±110.98^{a}	323.55±213.98^{b}	443.79±137.74^{ab}
Total energy (kJ/100 g)	1471.78±110.12^{a}	1655.60±230.87^{a}	1414.68±132.81^{a}

Dry powder's water activity: 0.50±0.00^{b} ('Wonderful'); 0.50±0.00^{c} ('Acco'); 0.52±0.00^{a} ('Herskovitz'). Values followed by different letters in the same row are significantly different at 5% level by Duncan Multiple Range Test.

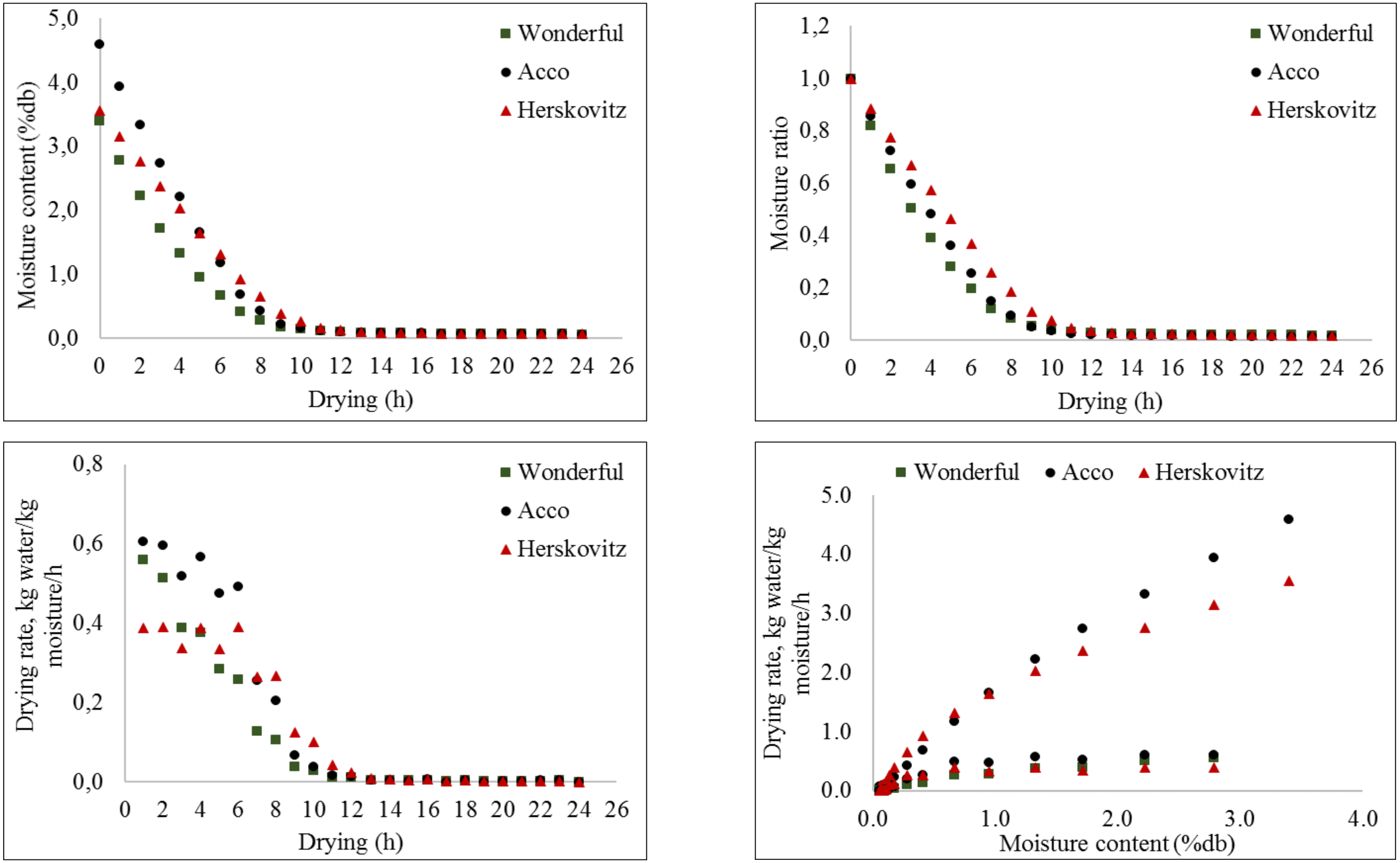

Fig. 1. Drying kinetics of arils of Wonderful, Acco and Herskovitz pomegranate cultivars

Initial moisture contents of arils were: 77.27±0.13%^{c} (3.40% db) (‘Wonderful’); 82.12±0.02%^{a} (4.59% db) (‘Acco’); 78.04±0.06%^{b} (3.55% db) (‘Herskovitz’).

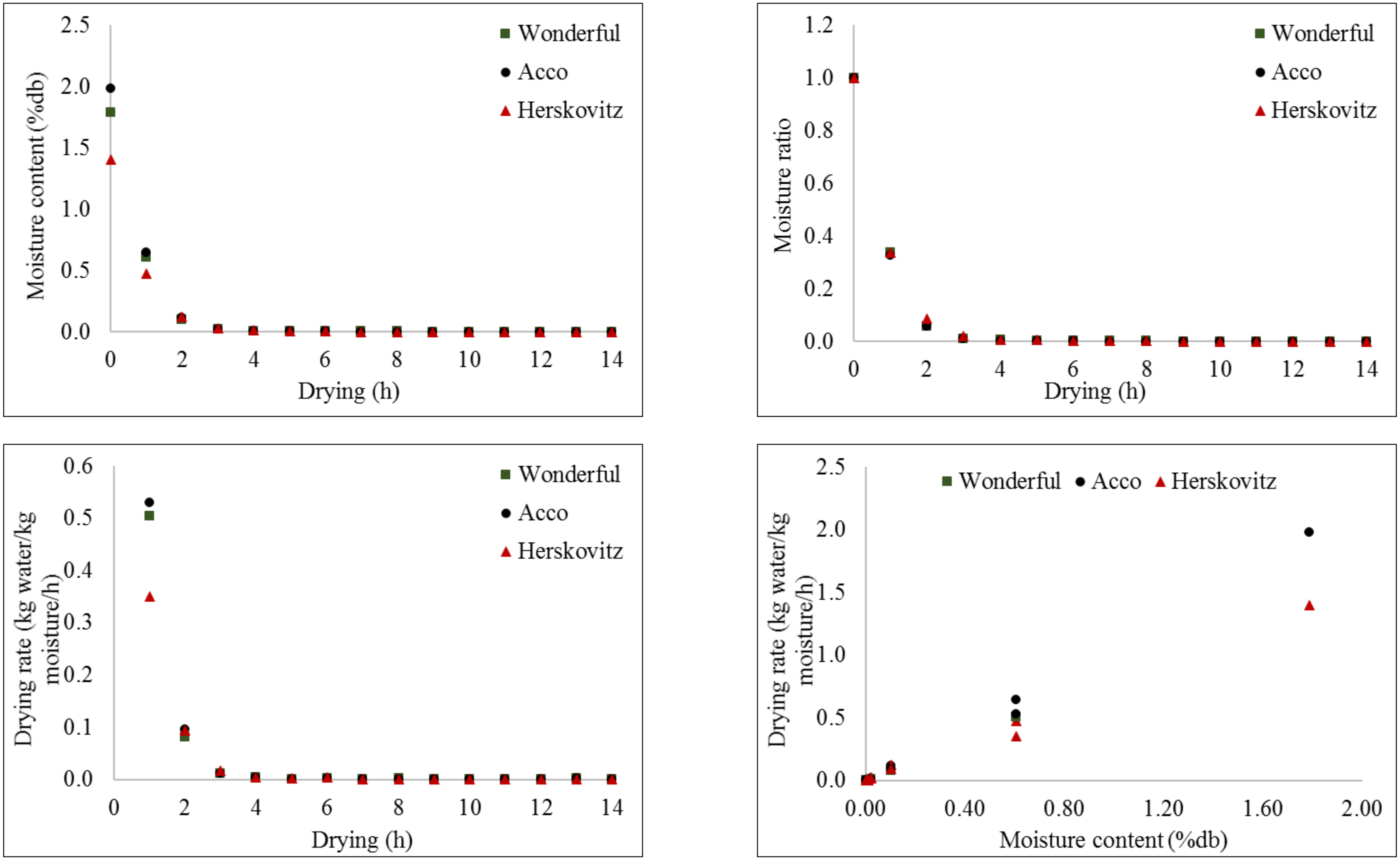

Fig. 2. Drying kinetics of conditioned kernels of Wonderful, Acco and Herskovitz pomegranate cultivars

Initial moisture contents of conditioned kernels were: 53.61±0.63%^{c} (1.16% db) (‘Wonderful’); 62.12±0.10%^{a} (1.64% db) (‘Acco’); 55.58±0.22%^{b} (1.25% db) (‘Herskovitz’).

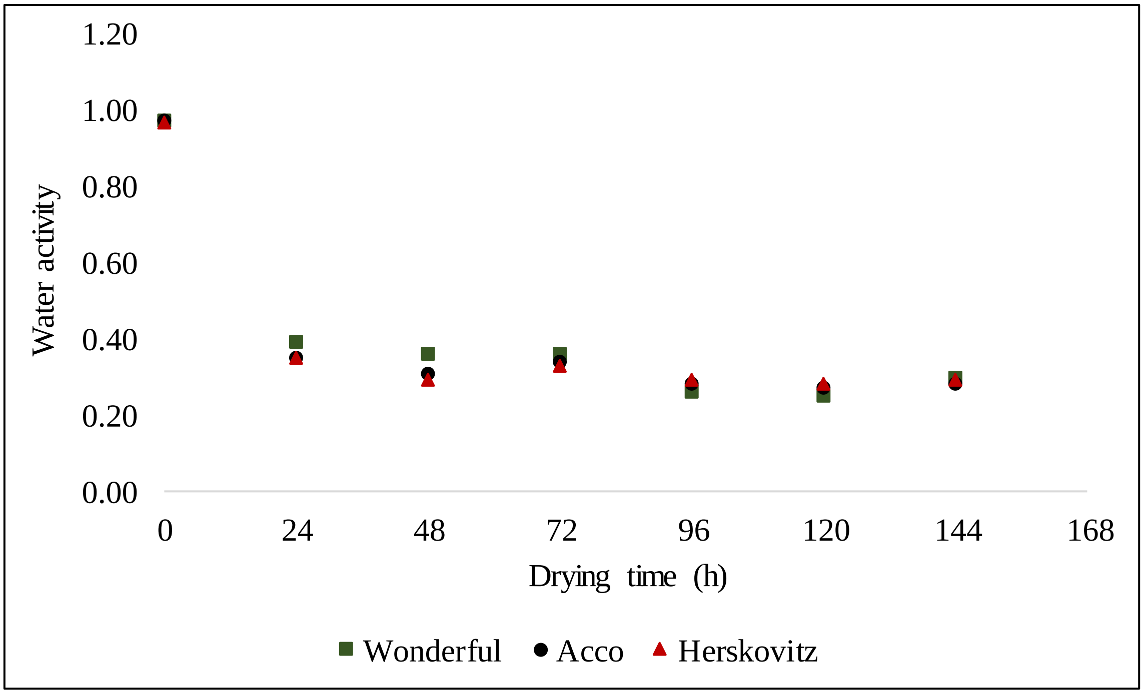

Fig. 3. Drying dependent water activity of arils of Wonderful, Acco and Herskovitz pomegranate cultivars

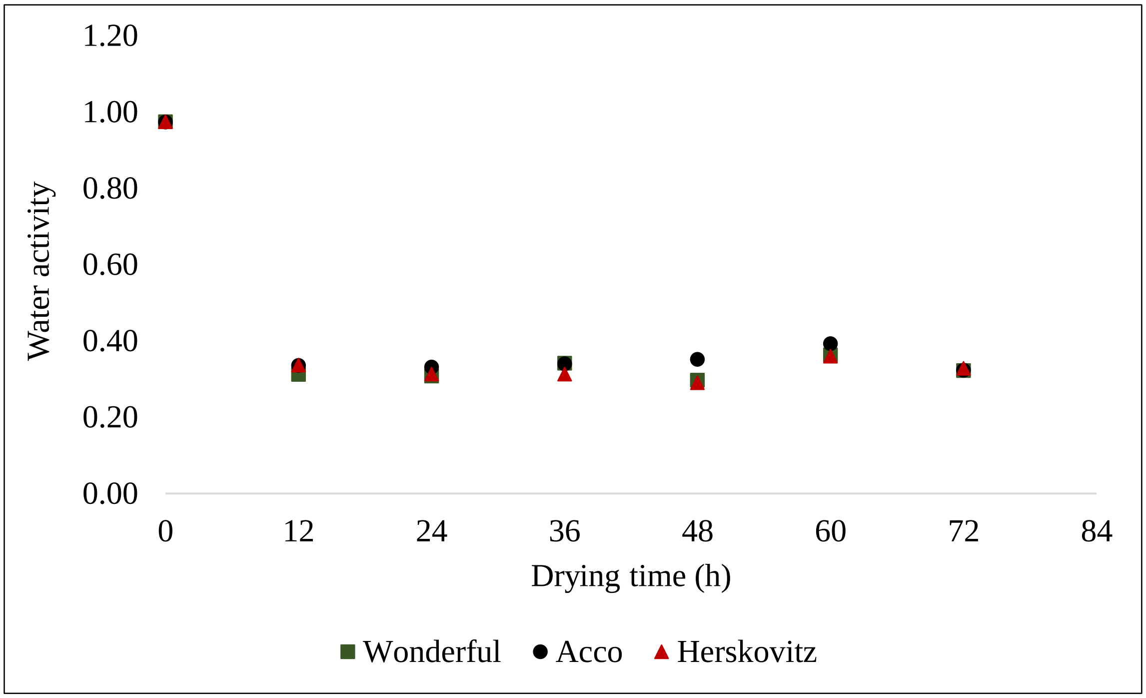

Fig. 4. Drying dependent water activity of conditioned kernels of Wonderful, Acco and Herskovitz pomegranate cultivars

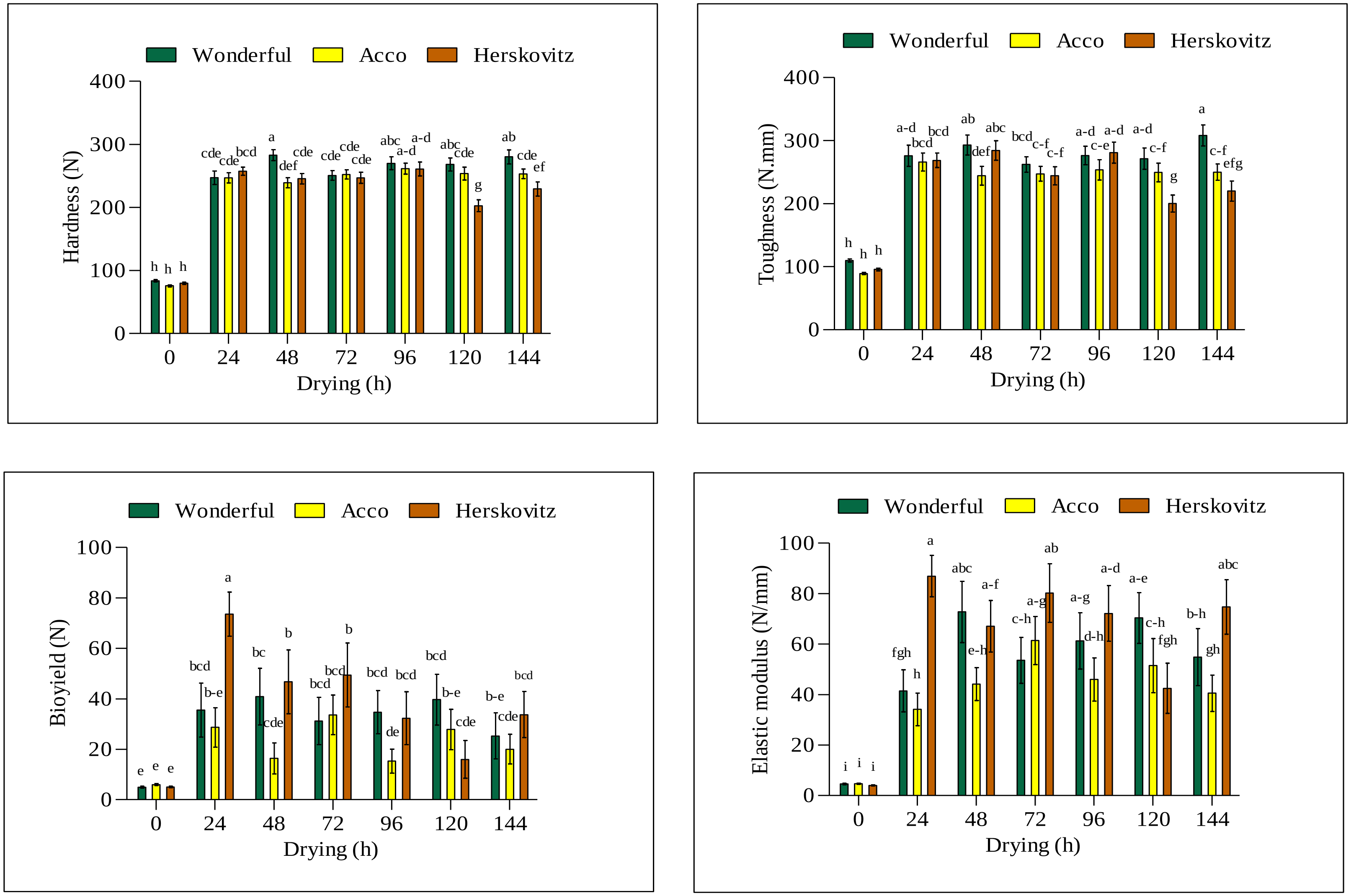

Fig. 5. Drying dependent textural properties of arils of Wonderful, Acco and Herskovitz pomegranate cultivars

Values followed by different letters in the same graph are significantly different at 5% level by Duncan Multiple Range Test.

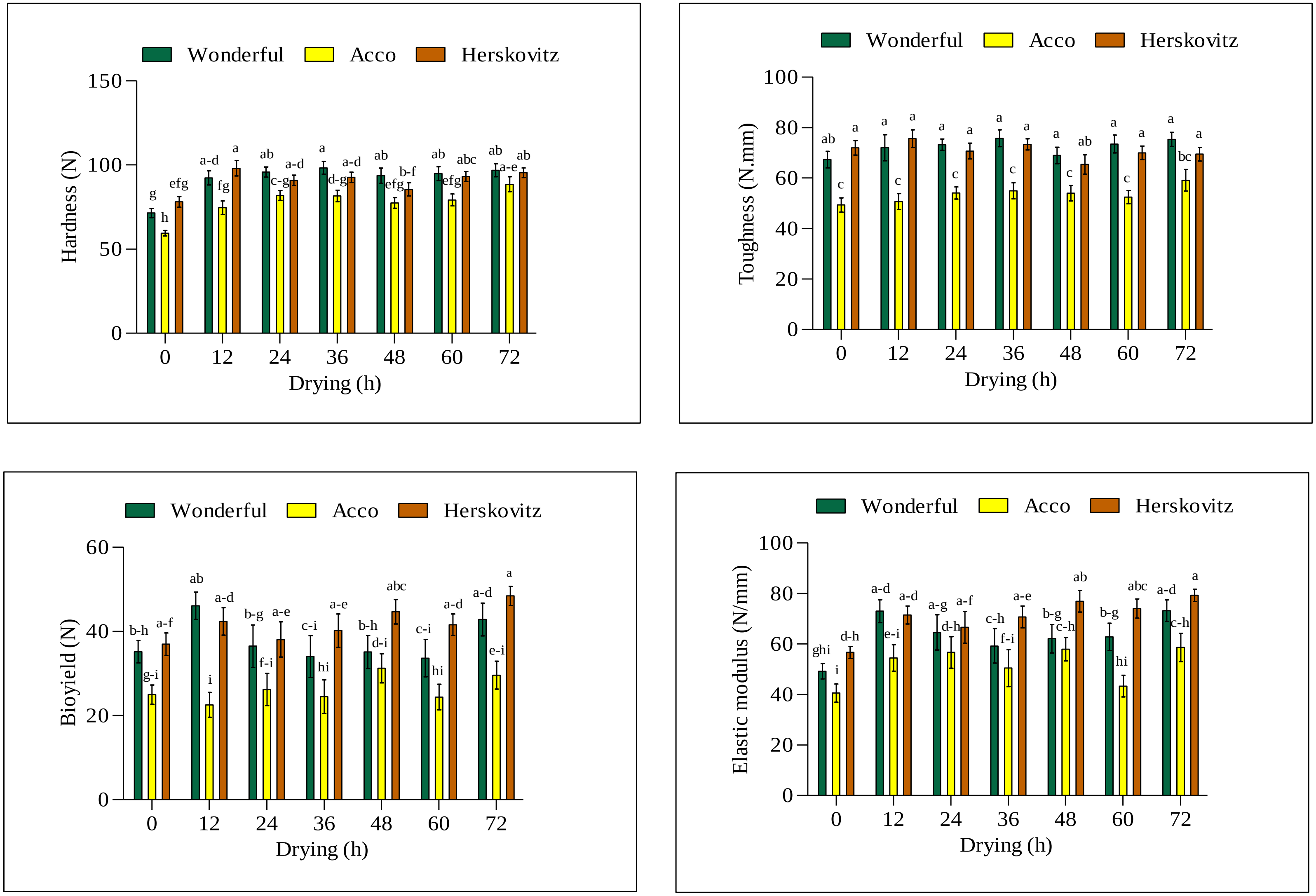

Fig. 6. Drying dependent textural properties of conditioned kernels of Wonderful, Acco and Herskovitz pomegranate cultivars Values followed by different letters in the same graph are significantly different at 5% level by Duncan Multiple Range Test.

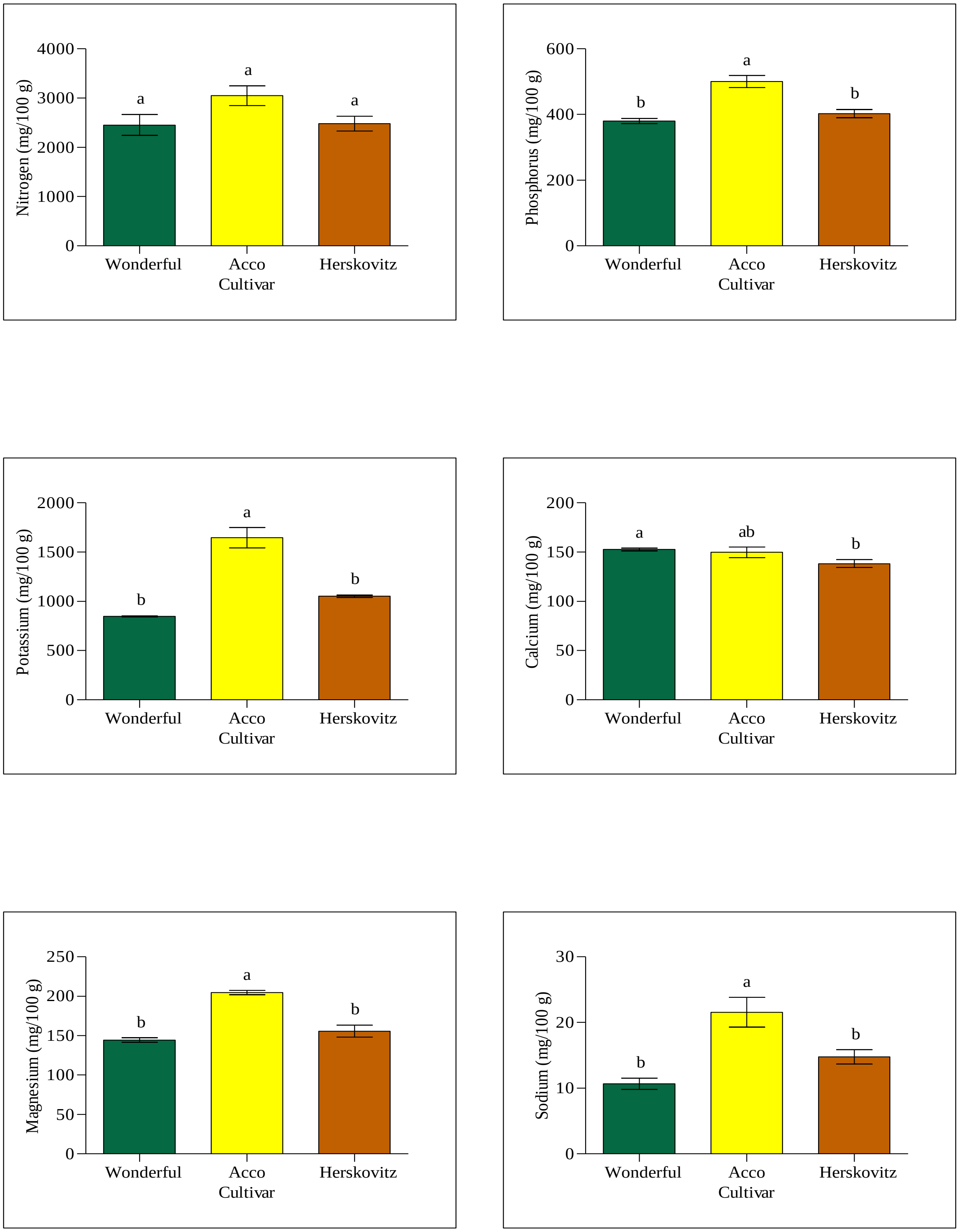

Fig. 7. Macro element contents (mg/100 g) in kernels of Wonderful, Acco and Herskovitz pomegranate cultivars

Values followed by different letters in the same graph are significantly different at 5% level by Duncan Multiple Range Test.

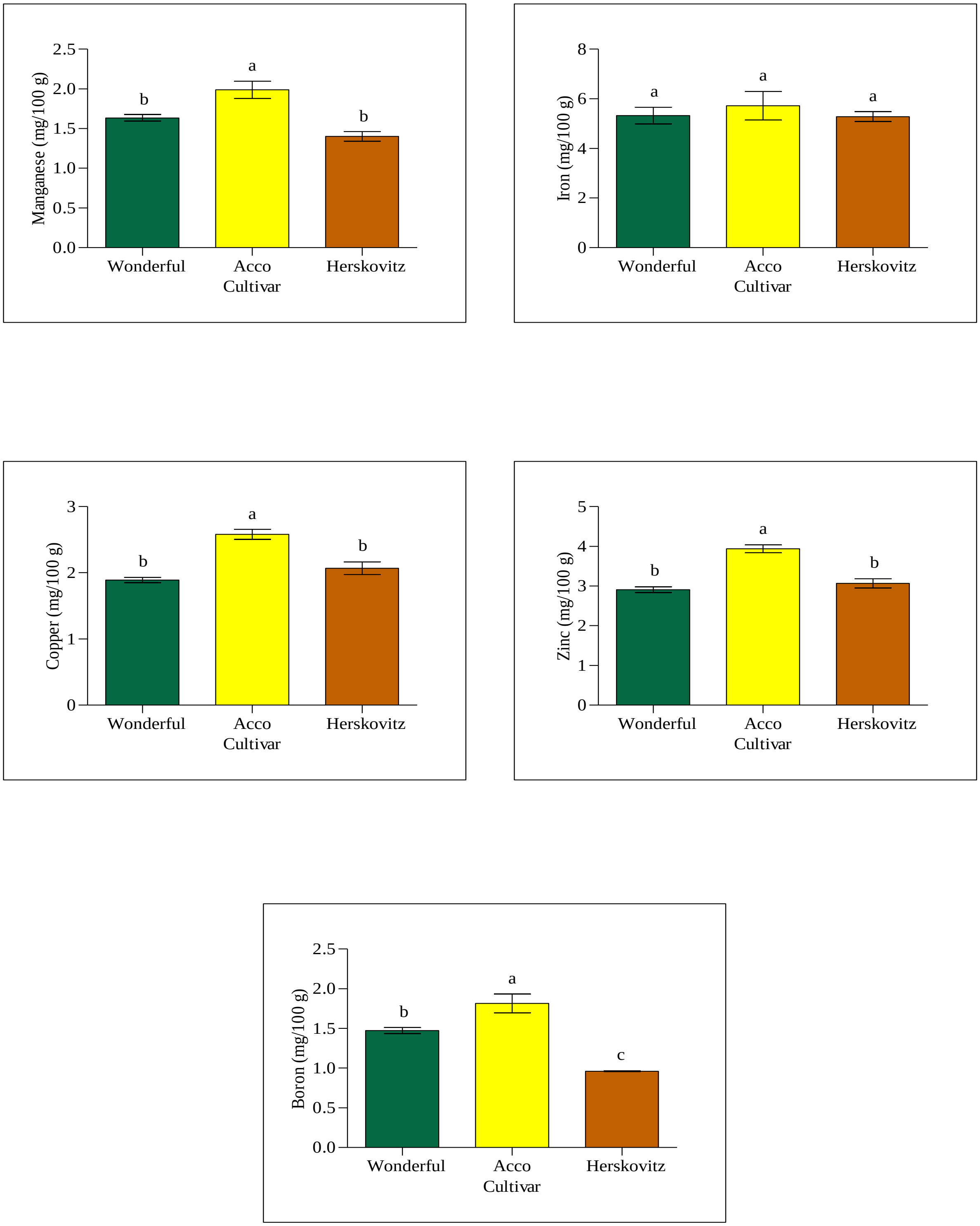

Fig. 8. Micro elements contents (mg/100 g) in kernels of Wonderful, Acco and Herskovitz pomegranate cultivars

Values followed by different letters in the same graph are significantly different at 5% level by Duncan Multiple Range Test.

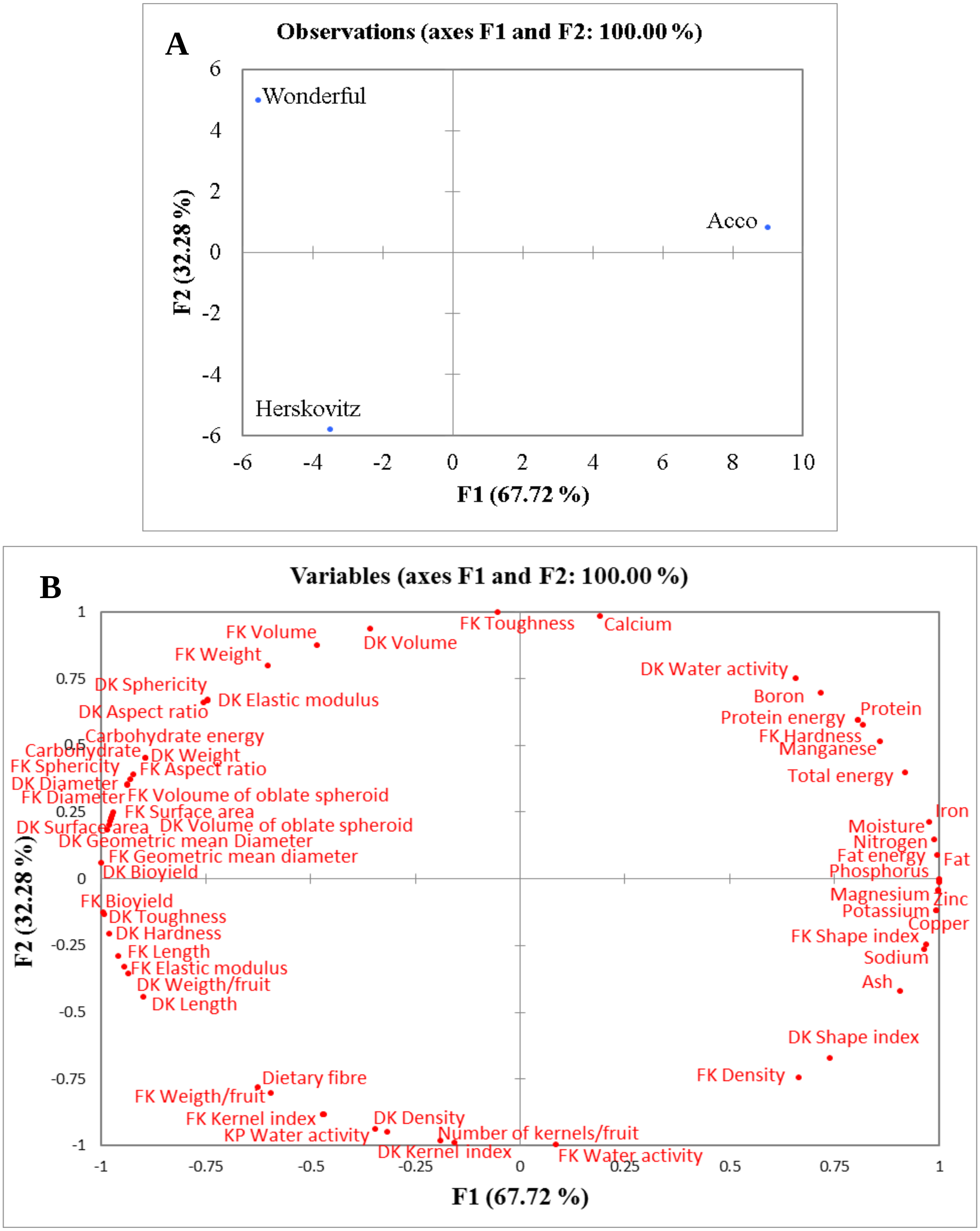

Fig. 9. Principal Component Analysis of F1 and F2 factors showing dispersion of properties of kernels of Wonderful, Acco and Herskovitz pomegranate cultivars; variable plot (**A**) and observation score (**B**) Fresh kernel (FK), Dried kernel (DK), Kernel powder (KP).

Chapter 5

Quality indices, bioactive content, fatty acid composition and stability of pomegranate kernel oil

QUALITY INDICES, BIOACTIVE CONTENT, FATTY ACID COMPOSITION AND STABILITY OF POMEGRANATE KERNEL OIL

Abstract

Pomegranate fruit has extensively been exploited by processors and nutritionists due to its health benefits. However, very little emphasis is focussed on the utilisation of waste generated during processing. This study investigated the value adding potential of pomegranate fruit with special interest on pomegranate kernel oil (PKO). Effects of extraction solvents namely; *n*-hexane, petroleum ether and acetone on the yield, quality attributes and fatty acid profile, as well as functional properties of PKO obtained from three commercially grown pomegranate cultivars were examined. The stability of PKO stored at 25°C and 60°C was also studied. The yield of PKO ranged between 16.59 – 27.39% and was in the order 'Acco' > 'Herskovitz' > 'Wonderful', regardless of extraction solvent. PKO extracted with acetone had the least yellow colour and high contents of phenolics, tocol, linolenic acids and *para*-anisidine value. Punicic acid was the predominant fatty acid (59.90 – 69.85%) in PKO investigated. However, punicic acid content varied with extraction solvents, in the order petroleum ether > *n*-hexane > acetone. All investigated PKO showed good radical scavenging activity (89.50 – 91.60%). Moreover, storage temperature of PKO affected its quality attributes and functional properties. PKO stored at 60°C contained higher levels of conjugated dienes and trienes and *para*-anisidine value compared with those stored at 25°C. Furthermore, there was a remarkable reduction in punicic acid and increment in α- and γ-linolenic acids in PKO stored at 60°C. Nonetheless, the low values of index of atherogenicity (0.04 – 0.05) and thrombogenicity (0.02 – 0.04) of PKO stored for 30 days indicated that the oil may still be safe for consumption, regardless of 25°C or 60°C storage temperature. This study provided basis for exploration of pomegranate oil for commercial applications in food, nutraceutical and cosmeceutical industries.

Keywords: Antioxidant, *para*-Anisidine, Pomegranate, Punicic acid, Ultrasonication

1. Introduction

Pomegranate has gained extensive applications in several cultures across the globe for its nutritional and medicinal properties (Seeram *et al.*, 2006; Opara *et al.*, 2009; Cohen, 2011; Casell, 2012; Da Silva *et al.*, 2013; O'Grady *et al.*, 2014). A typical pomegranate fruit can be divided into two fractions; edible and non-edible fractions. The edible part, which is mainly arils, contain juice and kernels. Prior to the past decade, nutritionists and processors focussed more on the juice extracted from the arils discarding the kernel. As a result, pomegranate kernels and their constituents were underutilised and rendered waste after processing (Kýralan *et al*., 2009; Modaresi *et al*., 2011; De Melo *et al*., 2014). In spite of this, current trends in research in recent years have shown that the kernels contain potentially edible and bioactive oil (Schubert *et al.*, 1999; Aviram *et al.*, 2000; Gil *et al.*, 2000; Melgarejo & Artes, 2000; Singh *et al.*, 2002; Murthy *et al.*, 2002; Arao *et al.*, 2004; Lansky *et al.*, 2005; Aslam *et al.*, 2006; Fadavi *et al.*, 2006; Seeram *et al.*, 2006; Lansky & Newman, 2007; Kaufman & Wiesman, 2007; Abbasi *et al.*, 2008; Moayedi *et al.*, 2011; Jing *et al.*, 2012; Viladomiu *et al.*, 2013; Khoddami *et al.*, 2014; Fernandes *et al*., 2015; Siano *et al.*, 2015).

According to literature, the amount of oil extracted from pomegranate varied considerably (0.25 – 27.20%) and this was dependent on extraction methods and pomegranate cultivars (El-Nemr *et al.*, 1990; Al-Maiman & Ahmad, 2002; Dangoggo *et al*., 2012). Pomegranate kernel oil (PKO) is characterised by conjugated fatty acids with punicic acid constituting over 60% of the fatty acids content (Aslam *et al*., 2006; Fadavi *et al*., 2006; Seeram *et al*., 2006; Lansky & Newman, 2007; Jing *et al*., 2012; Viladomiu *et al.*, 2013). In addition, PKO have been reported having 4.2 – 33.8% saturated and 66.2 – 95.8% unsaturated fatty acids (El-Shaarawy & Nahapetian, 1983; Melgarejo *et al.*, 1995; Melgarejo & Artes, 2000). On the contrary, El-Nemr *et al.* (1990) identified 83.6% saturated and 16.3% unsaturated fatty acids in PKO. This suggests that quality attributes, fatty acid profile and functional properties of PKO may vary depending on cultivar, method of oil extraction, as well as conditions and storage of the oil prior to analysis (Khoddami *et al.*, 2014). For instance, Akbari *et al.* (2014) observed that higher quality PKO can be extracted by cold press than with *n*-hexane. However, oil extracted with *n*-hexane had higher content of linoleic and linolenic fatty acids. This has encouraged the use of *n*-hexane to extract PKO in medical and cosmeceutical industries (Akbari *et al.*, 2014).

Furthermore, the effects of other extraction techniques, such as supercritical CO_2 extraction, superheated-hexane, subcritical propane, ultrasonic and soxhlet-assisted solvent extraction, as well as conventional ways of extracting oil using chemical solvents of varying polarity have all been explored on the overall quality of PKO extracted from cultivars harvested in different regions across the globe (Abbasi *et al*., 2008; Liu *et al*., 2009; Eikani *et al*., 2012; Ahangari & Sargolzaei, 2012; Tian *et al.*, 2013). However, no research has been conducted on the effect of extraction solvents of varying polarity on quality of PKO especially in the South African pomegranate industry. From commercial viewpoint, the aim of this study was to add value to pomegranate fruit by exploring oil from pomegranate kernel.

This was achieved by assessing the effect of extraction solvents on the yield, quality and functional properties of PKO. These properties were used to characterise major commercial pomegranate cultivars (‘Wonderful’, ‘Acco’ and ‘Herskovitz’) for value adding potential of oil extracted from them. In addition, the study also investigated temperature-related-stability of the extracted PKO.

2. Materials and methods

2.1. Sample preparation

Pomegranate fresh kernels were manually extracted from arils using a cheesecloth. The kernels were washed in distilled water to remove aril membrane before drying in an oven (Model OTE 160L, PROLAB, South Africa) operated at 60°C and 1.0 m/s air velocity. Drying was terminated when there was no change in kernel weight. Dried pomegranate kernels were grounded into fine powder using a miller (Model A11B, IKA, Germany). The dried kernel powder was then stored at -70°C until further analysis.

2.2. Oil extraction and yield

Pomegranate kernel oil was extracted from kernel powder using *n*-hexane, petroleum ether and acetone. In triplicates, pomegranate kernel powder (20 g) was weighed into a flask and extracted three times, 200 mL of solvent at a time, such that a total of 600 mL (3 x 200 mL) of each solvent was used The mixture was sonicated in a MRC ultrasonic bath (Model DC 400H, Haifa, Israel) operated at 40°C for 40 min. A flowchart of the extraction process is presented in Appendix: Chapter 5, Fig. 1. Oil filtrates from repeated extractions were pooled and air-dried under a stream of air in a fume hood. Oil yield was calculated using equation 1. PKO was transferred into a 1.5 mL Eppendorf tube and stored at -20°C until further analysis (Appendix: Chapter 5, Fig. 2A-2C).

$$\text{Yield (\%)} = \frac{\text{Weight of oil}}{\text{Weight of kernel powder}} \times 100 \qquad (1)$$

2.3. Oil quality indices

2.3.1. Colour attributes

Colour attributes of PKO were evaluated in CIE $L^*a^*b^*$ coordinates using a calibrated Minolta Chroma Meter, Model CR-400 (Japan). In replicates, PKO was transferred into a clear, glass vial and placed on a white board before measurement. Other colour attributes such as chroma (C^*) for colour intensity and hue angle ($h°$) for colour purity, were calculated using equations 2 and 3, respectively.

Chroma, $C^* = (a^{*2} + b^{*2})^{1/2}$ (2)

Hue angle, $h° = \text{Arc tan}\left(\frac{b*}{a*}\right)$ (3)

2.3.2. Refractive index

Refractive index (RI) of PKO was measured using a calibrated Abbé refractometer, Model 302 (ATAGO Co. Ltd., Japan) at 25°C room temperature (AOAC, 2012). Three drops of PKO were loaded on the refractometer prism and petroleum ether was used to clean the prism after each RI reading. The refractive indices of PKO recorded were expressed as mean ± S.E ($n = 3$).

2.3.3. Conjugated dienes and trienes

Conjugated dienes and trienes were measured according to the AOAC Ti 1a-64 (Firestone, 1994) with modifications (Bachari-Saleh *et al.*, 2013). PKO (20 mg) was dissolved in 7.0 mL isooctane and shaken in a water bath at 40°C to dissolve the oil. The mixture after cooling was made up to a volume of 10 mL with isooctane and this was vortexed and further diluted to a total volume of 40 mL (0.5 g/L PKO). Accurately, 3 mL of the diluted solution was transferred into a quartz cuvette and absorbance was measured at 233 nm and 268 nm for conjugated dienes and trienes, respectively, using a Helios Omega spectrophotometer (Thermo Fisher Scientific, Madison, USA). Isooctane was used as a blank. Units of conjugated dienes and trienes of PKO were calculated using equations 4 and 5, respectively. All results were presented as mean ± S.E ($n = 3$).

$$\text{CD (unit)} = \frac{\text{Absorbance of PKO mixture at 233 nm}}{\text{Cuvette length (cm)} \times \text{Concentration of final dilution}} \quad (4)$$

$$\text{CT (unit)} = \frac{\text{Absorbance of PKO mixture at 268 nm}}{\text{Cuvette length (cm)} \times \text{Concentration of final dilution}} \quad (5)$$

2.3.4. *para*-Anisidine value

This was carried out in accordance with AOAC Cd 18-90 (Firestone, 1994). Briefly, PKO (0.5 g) was dissolved in 25.0 mL isooctane followed by absorbance measurement of the resulting PKO solution at 350 nm using a Helios Omega spectrophotometer (Thermo Fisher Scientific, Madison, USA). Isooctane was used as a blank. After absorbance measurements, 5.0 mL aliquot of the resulting mixture was pipetted into a glass test tube followed by the addition of 1.0 mL *para*-anisidine (*p*-anisidine) reagent (0.25 g *p*-anisidine prepared in 100 mL glacial acetic acid). The mixture was vortexed, incubated for 10 min at 25°C room temperature and the absorbance measured at 350 nm. The blank constituted a mixture made up of 5.0 mL isooctane and a 1.0 mL *p*-anisidine reagent. *p*-Anisidine value (*p*-AV) was calculated using equation 6. The final results were reported as mean ± S.E ($n = 3$).

$$p\text{-AV} = \frac{25 \times [(1.2 \times \text{Abs of PKO solution with } p\text{-anisidine reagent}) - \text{Abs of PKO solution}]}{\text{Weight of PKO}} \quad (6)$$

2.4. Bioactive content and radical scavenging activity

2.4.1. Total phenolic content

Folin-Ciocalteau assay originally described by Abbasi *et al.* (2008) was adapted for this analysis. In brief, PKO (0.5 g) was dissolved in 5.0 mL 50% aqueous methanol to prepare test samples. An aliquot of 2.0 mL from the resulting solution was pipetted into a 100 mL volumetric flask followed by the addition of 0.5 mL of Folin-Ciocalteau reagent, 1.0 mL of anhydrous 35% Na_2CO_3 and 96.5 mL of distilled water. The mixture was vortexed and the absorbance read at 760 nm after 30 min incubation in the dark. A standard curve consisting of 0.02 – 0.10 mg/mL gallic acid was prepared following the same procedure. Total phenolic content (TPC) of PKO was extrapolated and reported as milligram gallic acid equivalent (mg GAE/g oil). Blank test for the assay consisted of reaction mixture without PKO or gallic acid. The results were presented as mean ± S.E ($n = 3$).

2.4.2. Total carotenoid content

Total carotenoid content was evaluated in accordance to AOAC 958.05 assay (AOAC, 2012) with modifications proposed by Biehler *et al*. (2010) and Siano *et al*. (2015). In brief, PKO (0.1 mL) was dissolved in 10 mL dimethyl sulfoxide (DMSO). The total carotenoid content (TCC) of the resulting mixture was estimated following absorbance readings at 440 nm and 460 nm, with DMSO solvent as the blank. TCC for each wavelength was calculated using equations 7 and 8. All experimental findings were expressed as mean ± S.E ($n = 3$) β-carotene/kg oil.

$$\text{TCC}_{440\text{ nm}}\ (\text{g/kg}) = \frac{\text{Abs }(440\text{ nm}) \times \text{Dilution factor} \times \text{Cuvette length} \times \text{Mwt }(\beta\text{-carotene})}{\text{Average molar absorption coefficient}} \quad (7)$$

$$\text{TCC}_{460\text{ nm}}\ (\text{g/kg}) = \frac{\text{Abs }(460\text{ nm}) \times \text{Dilution factor} \times \text{Cuvette length} \times \text{Mwt }(\beta\text{-carotene})}{\text{Average molar absorption coefficient}} \quad (8)$$

TCC = Total carotenoid content; Molar absorption coefficient = 135310; Dilution factor =101, Cuvette length = 4 cm; Molecular weight (Mwt) = 536.87 g/mol

2.4.3. Radical scavenging activity

The ability of PKO to scavenge 2,2-diphenyl-1-picrylhydrazyl (DPPH) stable free radical was measured according to Brand-Williams *et al.* (1995) with modifications (Siano *et al.*, 2015). PKO (0.1 mL) was dissolved in 10 mL dimethyl sulfoxide (DMSO) and 0.1 mL of the mixture was transferred into a test tube followed by the addition of 2.4 mL DPPH solution (0.1 mM). The mixture was vortexed, incubated in the dark for 30 min and the absorbance read at 517 nm. Following the same procedure, trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), a standard antioxidant, was used as a positive control while negative control and blank were DPPH solution and DMSO solvent, respectively. DPPH radical scavenging activity (%RSA) was calculated according to equation 9. All data were presented as mean ± S.E (n = 3).

$$\text{RSA (\%)} = \left(1 - \frac{\text{Absorbance of reaction mixture}}{\text{Absorbance of DPPH solution}}\right) \times 100 \qquad (9)$$

2.4.4. Fatty acids, triterpene, tocol and phytosterol profile

Gas Chromatography-Mass Spectrometry (GC-MS) method described by Mphalele (2016) was adopted for this analysis. PKO (0.1 g) was weighed into a 15 mL plastic vial followed by the addition of 2.0 mL hexane, 50 µL heptadecanoic acid (1000 ppm) as internal standard and 1.0 mL of 2.5% H_2SO_4. The reaction mixture was vortexed and incubated at 80°C for 1h in an oven. The mixture was cooled followed by the addition of 1.5 mL of 20% NaCl and this was vortexed to extract fatty acids methyl esters (FAME), triterpene, tocol and phytosterol. The supernatant containing hexane phase was collected into a glass vial and analysed using a GC-MS (6890N, Agilent technologies network) coupled to an Agilent technologies inert XL EI/CI Mass Selective Detector (MSD) (5975B, Agilent technologies Inc., Palo Alto, CA), with helium gas employed as the carrier gas at a flow rate of 0.017 mL/s. One microlitre of sample was injected in a split ratio of 10:1. The oven temperature was run as: 100°C/min, 180°C at 25°C/min and held for 3 min, 200°C at 4°C/min and held for 5 min, 280°C at 8°C/min, and 310°C at 10°C/min and held for 5 min. All detected constituents of PKO were identified using the NIST library. Results were expressed as a mean area percentage ± S.E (n = 3). Summations (∑) of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), unsaturated fatty acids (UFA), as well as the ratios between the fatty acids were derived from the GC-MS primary data. Index of atherogenicity (IA) and thrombogenicity (IT) were calculated using equations 10 and 11, respectively (Ulbritch & Southgate, 1991; Senso *et al.*, 2007; Garaffo *et al.*, 2011).

$$\text{IA (\%)} = \frac{[(4 \times \text{C14:0}) + \text{C16:0} + \text{C18:0}]}{[\sum\text{MUFA} + (\sum\text{PUFA} - \omega6) + (\sum\text{PUFA} - \omega3)]} \qquad (10)$$

$$\text{IT (\%)} = \frac{\text{C14:0} + \text{C16:0} + \text{C18:0}}{[(0.5\times\sum\text{MUFA}) + [(0.5\times\sum\text{PUFA}) - \omega6] + [(3\times\sum\text{PUFA}) - \omega3] + \left(\frac{\sum\text{PUFA}-\omega3}{\sum\text{PUFA}-\omega6}\right)]} \qquad (11)$$

2.5. Oil stability test

Stability of PKO was assessed during a 30-day storage period. In other to accelerate chemical changes in PKO, 3 mL of PKO test samples was transferred into a glass vial and stored in an oven (Model OTE 160L, PROLAB, South Africa) operated at 60°C and 1.0 m/s air velocity. PKO stored at ambient temperature (25°C) was used as a control test. All attributes including quality indices, bioactive contents, radical scavenging activity and fatty acid profile of PKO were measured at 10 days intervals using the same experimental procedure and conditions as described in the materials and methods section.

3. Statistical analysis

Statistica 64, version 13 was used for two-way Analysis of Variance (ANOVA) and Duncan Multiple Range Test (DMRT) was used to separate means at 5% confidence level. Two-way ANOVA helped to comprehend the interaction between two or three independent variables (cultivar and extraction solvent and/or processing) and dependent variable (oil property). Similarly, DMRT helped to categorize means of oil property into significant and non-significant groups. Graphs were presented using GraphPad Prism, version 5.00 (GraphPad Software, San Diego, USA). Principal Component Analysis (PCA), obtained by subjecting all experimental data to XLSTAT software version 2012.04.1 (Addinsoft, France), was used to explore correlations between the investigated oil properties and pomegranate cultivars.

4. Results and discussion

4.1. Oil yield

Varying amounts of oil constituting 0.5 – 0.8% of pomegranate whole fruit weight were obtained from pomegranate kernels using different extraction solvents, with oil yield ranging between 16.59 – 27.39%. *n*-Hexane and acetone extracted the highest and lowest oil yield, respectively. However, among cultivars, the order was ‘Acco’ > ‘Herskovitz’ > ‘Wonderful’ (Fig. 1). In comparison, PKO extracted from Chinese pomegranate cultivars, regardless of extraction solvents, ranged between 18.56

and 20.67% (Tian *et al*., 2013), which are within the range obtained in the present study for 'Wonderful' (16.59 – 17.95%) and 'Herskovitz' (17.06 – 19.76%) whereas Acco cultivar yielded higher amount of oil (23.99 – 27.39%) than those reported by Tian *et al*. (2013). However, Jing *et al*. (2012) and Mekni *et al*. (2014) reported lower oil yield using *n*-hexane (11.42 – 14.79%) and petroleum ether (17.95 – 27.39%), respectively. Furthermore, factorial analysis showed that yield of PKO was cultivar dependent ($p < 0.0001$) as opposed to extraction solvent ($p = 0.5300$) (Appendix: Chapter 5, Table 2). Overall, this suggests that, aside extraction solvents, kernel source in terms of cultivar could play a role in the amount of oil obtained from pomegranate kernel. As such, in terms of yield, Acco cultivar could be considered most desirable for commercial exploration of oil from pomegranate kernels.

4.2. Oil indices

4.2.1. Colour attributes

Colour plays a vital role in marketability of oil since it is one of the major visual traits that defines its acceptance. Table 1 presents colour attributes of all investigated PKO. The CIE colour indicators were influenced by extraction solvent except a^* value (Appendix: Chapter 5, Table 1). Among the colour parameters, a positive b^* value indicates yellowness thus, the most suitable attribute to assess the characteristic yellow colouration of any oil including PKO. In particular, with significantly ($p < 0.05$) higher b^* values, PKO extracted with *n*-hexane and petroleum ether appeared more yellow than those extracted with acetone, regardless of cultivar (Table 1). This observation was also supported by colour saturation (C^*) and lightness (L^*), where significantly ($p < 0.05$) higher values were obtained for PKO extracted with *n*-hexane and petroleum ether than PKO extracted with acetone, regardless of cultivar (Table 1). In comparison with the study by Khoddami *et al.* (2014), PKO in this current study possess lower yellow coloration ($b^* = 14.10 – 36.86$) compared with PKO obtained by cold press from Iranian Torshe Malas cultivar ($b^* = 46.62$). This disparity could be due to differences in cultivar and extraction methods.

4.2.2. Refractive index

There were no significant differences in refractive index (RI) of PKO, regardless of extraction solvent and cultivar (Table 2). Since RI is based on density of a substance, it could be suggested that the solvents used extracted PKO of similar densities. This is in part contrary to Moreno *et al*. (2003) who reported that chemical solvents used in oil extraction could influence the RI of the oil.

4.2.3. Conjugated dienes and trienes and *para*-anisidine value

Oxidation of lipids begins with the production of hydroperoxides followed by rearrangement of non-conjugated bonds to generate conjugated dienes (CD) and trienes (CT) (Poiana, 2012). As a result, CD and CT provide a measure that is used to quantify primary and secondary oxidation products, respectively, in oil undergoing oxidation (Karleskind, 1992; Besbes *et al*., 2005). CT units (0.78 – 0.81) were two folds more than CD units (0.23 – 0.52). This may be an indication of rapid rate of carbonyls formation in line with autoxidation of unsaturated fatty acids present in the investigated PKO. It is however unclear if this was due to extraction solvent or cultivar as the interaction between extraction solvent and cultivar was significant ($p < 0.0001$) (Appendix: Chapter 5, Table 2).

The formation of hydroperoxides such as CD and CT in oxidation of lipids is lagged by the production of secondary oxidation products. These secondary oxidation products are carbonyls (aldehydes, ketones and carboxylic acids) and are responsible for the development of off-flavours and odours in edible oil undergoing rancidity (Poiana, 2012). According to Zhang *et al*. (2010) and De Abreu *et al*. (2010), *para*-anisidine value (*p*-AV) is a reliable test for quantifying carbonyl compounds in edible oils. Factorial analysis showed that oxidation of PKO, in terms of *p*-AV, was influenced by both the extraction solvent ($p < 0.0001$) and cultivar ($p < 0.0001$) (Appendix: Chapter 5, Table 2). In particular, PKO of 'Herskovitz' had the highest *p*-AV, regardless of extraction solvent (Table 2). This could be a reflection of its stability and shelf life (Poiana, 2012) since all PKO were extracted from the three cultivars at the same time. With reference to extraction solvent, *p*-AV in relation to oxidation of PKO were in order of acetone > *n*-hexane > petroleum ether (Table 2). *p*-AV (3.94 – 11.66) reported in the present study are comparable with those reported for cold press PKO of Iranian 'Torshe Malas' (4.70) and commercial PKO (5.96 – 6.23) purchased from Iran and Turkey (Khoddami *et al.*, 2014).

4.3. Oil chemical properties

4.3.1. Total phenolic content

Total phenolic content (TPC) of PKO was influenced by the combined effects of cultivar ($p < 0.0001$) and extraction solvent ($p < 0.0001$) (Appendix: Chapter 5, Table 2). In particular, TPC was in the order acetone **>** *n*-hexane **>** petroleum ether, with cultivar in the order 'Acco' > 'Herskovitz' > 'Wonderful' (Table 2). In comparison with other studies, TPC obtained in this study (0.43 – 8.58 mg GAE/g) were higher than those reported for PKO of Italian cultivar extracted using Soxhlet assisted diethyl ether solvent (Siano *et al*., 2015) whereas, similar TPC (10.44 mg GAE/g) was reported for PKO extracted by cold press from Iranian ‘Torshe Malas’ (Khoddami *et al.*, 2014). However, commercial PKO has been reported to vary between 8.52 – 9.16 mg GAE/g TPC (Khoddami *et al.*, 2014), which are much higher than those obtained in the present study.

The presence of phenolic compounds in PKO has generated a lot of interest among researchers due to their functional properties (Yu *et al.*, 2005; Aydeniz *et al.*, 2014; Khoddami *et al.*, 2014). Studies have suggested that antioxidant capacity of PKO could in part be attributed to the appreciable amount of TPC in the oil (Moayedi *et al.*, 2011; Khoddami *et al.*, 2014; Siano *et al.*, 2015). According to Mekni *et al.* (2014), phenolic compounds obtained from PKO are as a result of them leaching from pomegranate kernel into the oil during extraction. This suggests that the amount of phenolic compounds leached into PKO will depend on their concentration in pomegranate kernel and the ability to extract these phenolic compounds from the kernels during oil extraction process. This further buttresses our findings that TPC of PKO was dependent on both extraction solvent and cultivar.

4.3.2. Total carotenoid content

Knowledge of carotenoid content in oil is relevant to its functional and nutraceutical properties. The total carotenoid content (TCC) measured at 440 and 460 nm did not follow any specific trend (Table 2). This is evidenced by significant interaction effect between extraction solvent and cultivar (Appendix: Chapter 5, Table 2). Overall, a range of 0.10 – 0.30 g β-carotene/kg was obtained in PKO of ‘Wonderful’, ‘Acco’ and ‘Herskovitz’. TCC found in this study were higher than those reported for PKO (440 nm = 31.5 µg β-carotene/kg; 460 nm = 29.1 µg β-carotene/kg) extracted using Soxhlet assisted diethyl ether solvent (Siano *et al.*, 2015). In comparison with other types of oil, TCC in oils such as cherry, pumpkin and date palm oils were lower than TCC ranges provided in this study (Nehdi *et al.*, 2010; Siano *et al.*, 2015). Carotenoids have been implicated in various biological activities (Amorim-Carrilho *et al.*, 2014; Saini *et al.*, 2015) including skin regeneration and anti-aging (Curl, 1964; Biehler *et al.*, 2010; Jing *et al.*, 2012). Given its high TCC, PKO could be desirable for various applications in cosmeceutical and beauty industry. This further shows that all investigated PKO could be exploited for its high carotenoid content.

4.3.3. Antioxidant capacity

DPPH radical scavenging activity (RSA) of PKO was cultivar dependent (Appendix: Chapter 5, Table 2) and ranged between 89.50 – 91.60% in order of ‘Herskovitz’ > ‘Wonderful’ > ‘Acco’ (Table 2). Scavenging activity of PKO has been attributed to its high TPC (Murthy *et al.*, 2002; Yu *et al.*, 2005;

Aydeniz *et al*., 2014). In addition to TPC, carotenoids in pomegranate oil have also been implicated in the oil radical scavenging activity (Amorim-Carrilho *et al*., 2014; Saini *et al*., 2015; Yan *et al*., 2016). The high RSA (%) exhibited by the investigated oils in this study may be a reflection of its high phenolic and carotenoid contents. RSA of this study was similar to scavenging activity (96.80%) reported for PKO extracted using Soxhlet assisted diethyl ether solvent from Italian pomegranate cultivar (Siano *et al*., 2015). In comparison with other oil types, PKO in this study exhibited higher RSA than pumpkin oil (25.87%) (Siano *et al*., 2015). This further suggests the potential of pomegranate oil as a natural bioactive and functional product and a possible replacement of synthetic compounds in cosmeceutical and food industries. For instance, oil obtained by cold press of yeast fermented pomegranate kernels was reported having antioxidant activity as strong as butylated hydroxyanisole (Schubert *et al*., 1999).

4.3.4. Fatty acids, triterpene, tocol and phytosterol profile

An investigation of the compositions of three solvents assisted extractions of PKO of ‘Wonderful’, ‘Acco’ and ‘Herskovitz’ and their health-related indices were conducted in order to provide nutritional evaluation of the oil samples. There were no qualitative differences in fatty acids (FA) observed among the examined oil samples (Table 3). Palmitic acid was the most predominant saturated fatty acids (SFA) followed by stearic and arachidic acids in all investigated oil samples. Among SFA, only stearic acid was cultivar (p < 0.0001) dependent (Appendix: Chapter 5, Table 3). Three monounsaturated fatty acids (MUFA); vaccenic (0.42 – 0.86%), goindoic (0.31 – 0.78%) and oleic acid (3.66 – 5.97%), as well as four polyunsaturated fatty acids (PUFA); linoleic (5.22 – 7.49%), punicic (59.90 – 69.85%), α-linolenic (0.57 – 4.84%) and γ-linolenic acids (1.17 – 4.10%) were also identified (Table 3). Overall, punicic acid, a conjugated linolenic acid unique to pomegranate, was the predominant fatty acid and its content was influenced by cultivar (p < 0.0001) (Appendix: Chapter 5, Table 3). The abundance and variations of punicic acid in PKO form different pomegranate cultivars is in agreement with previous findings (Elfalleh *et al*., 2011; Eikani *et al*., 2012; Verardo *et al*., 2014). In terms of extraction solvents, relative abundance of punicic acid was in the order petroleum ether > *n*-hexane > acetone (Table 3). Furthermore, among the investigated extraction solvents, PKO extracted with acetone yielded the highest amounts of α- and γ-linolenic acids and this may be due to the higher polarity index of acetone.

Also, appreciable amounts of triterpene (squalene) (1.77 – 3.31%), tocol (γ-tocopherol) (2.11 – 7.27%) and phytosterol (γ-sitosterol) (2.16 – 5.11%) were obtained in the investigated PKO (Table 3), suggesting that PKO is rich in important bioactives. For instance, squalene is a precursor of important bioactives such as cholesterol, steroid hormones and vitamin D. In addition to this, squalene has an anti-carcinogenic property, serves as an immunologic adjuvant in vaccines and constitutes one of the integral components of some cosmeceuticals (Smith, 2000; Owen *et al.*, 2004). Furthermore, γ-tocopherol, which is generally known for its free radical scavenging capacity, is the most prevalent form of vitamin E in plant seed or kernel oil (McLaughlin & Weihrauch, 1979). The findings show that PKO extracted with acetone yielded greater levels of γ-tocopherol. Moreover, the relative abundance of γ-tocopherol which was cultivar dependent (Appendix: Chapter 5, Table 3), was in order of ‘Herskovitz’ > ‘Acco’ > ‘Wonderful’ (Table 3).

The total amounts of SFA (5.98 – 7.49%), MUFA (4.45 – 6.92%), PUFA (72.28 – 80.03%), UFA (77.72 – 84.77%), as well as the ratios in terms of SFA/UFA (0.07 – 0.10), SFA/MUFA (1.05 – 1.38), SFA/PUFA (0.07 – 0.10) and PUFA/MUFA (11.42 – 18.20) (Table 3) were within the ranges reported for oil extracted from pomegranate cultivars grown in different countries (Hernández *et al.*, 2000; Fadavi *et al.*, 2006; Akbari *et al.*, 2014; Siano *et al.*, 2015). Moreover, the index of atherogenicity (IA), which indicate the tendency of edible oil to adhere to cells of immunological and circulatory systems, and the index of thrombogenicity (IT), which illustrates clots of oil in blood vessels (Ulbritch & Southgate, 1991; Garaffo *et al.*, 2011), were 0.05% and 0.03%, respectively (Table 3). These indices are very low in all the investigated PKO, regardless of cultivar, hence safe for consumption. In comparison with literature, these indices are lower than those reported for sweet cherry oil (0.15% IA; 0.30% IT) and pumpkin oil (0.34% IA; 0.65% IT) (Siano *et al.*, 2015).

4.4. Stability of pomegranate kernel oil

4.4.1. Changes in quality indices of PKO

There were no significant ($p > 0.05$) changes in refractive index of the investigated oil stored at shelf condition (25°C) and 60°C for 30 days (data not shown). However, conjugated dienes and trienes increased with prolonged storage, with marked increases between Day 0 and Day 10 under both storage conditions (Table 4). Overall, this is an indication of more primary oxidation products in the investigated pomegranate oil subjected to storage conditions and durations, regardless of cultivar and extraction solvent. The production of secondary oxidation products is further confirmed by increase in *para*-anisidine value in stored pomegranate oil, especially in those stored at 60°C where accelerated oxidation is expected (Table 4). This indeed suggests that temperatures above ambient condition could promote formation of carbonyls (aldehydes, ketones and carboxylic acids) in PKO, which could eventually result in rancidity and developments of undesirable odours in PKO (Poiana, 2012).

4.4.2. Changes in chemical properties of PKO

There were no significantly ($p > 0.05$) differences in total carotenoid content (TCC) monitored in PKO kept under two different storage temperatures however, oil stored at 60°C for 30 days contained more TCC (Table 5). There could be various reasons for this observation however; a logical explanation for increase in TCC of PKO after prolong storage could be due to concentration effect resulting from storage at temperature (60°C) above ambient condition. DPPH free radical scavenging activity (RSA) of PKO increased after 10 days of storage and stabilised afterwards. The RSA remained high ranging between 89.50 – 99.48% for all investigated PKO (Table 5). In addition, storage temperature (25°C vs. 60°C) did not significantly ($p > 0.05$) influence the radical scavenging activity of pomegranate oil. These high RSA activities could be associated with hydrophilic polyphenols, as well as lipid-soluble carotenoids and tocopherols, which are inherent in PKO (Siano *et al*., 2015).

Whilst the levels of several fatty acids remained steady for both storage temperature (25°C vs. 60°C) (Appendix: Chapter 5, Table 6), punicic and α- and γ-linolenic acids varied considerably for 60°C stored PKO (Table 6). As observed, the percentage abundance of punicic acid decreased with a simultaneous increment in levels of α- and γ-linolenic acids. This may be attributed to isomerization reactions among these three fatty acids. Nonetheless, punicic acid, α- and γ-linolenic acids were largely unaffected in PKO stored on at 25°C. Furthermore, significant decreases in γ-tocopherol and γ-sitosterol was monitored in PKO, regardless of the storage temperature (Table 6). Most importantly, the low values of index of atherogenicity (0.04 – 0.05) and index of thrombogenicity (0.02 – 0.04) of PKO suggest its safe consumption after the investigated storage temperature and duration (Appendix: Chapter 5, Table 6).

4.5. Principal Component Analysis result

The characteristic uniqueness of *n*-hexane, petroleum ether and acetone derived PKO of ‘Wonderful’, ‘Acco’ and ‘Herskovitz’ is illustrated on the Principal Component Analysis (PCA) biplot in Fig. 2. Factors 1 and 2 (F1 and F2) accounted for 38.01% and 24.80% variations in the investigated cultivars, respectively. In general, PKO extracted with acetone, regardless of cultivar, are characterised by tocol, *p*-AV, DPPH, TPC, squalene and several fatty acids on positive F1 plane. PKO of ‘Acco’ are associated with higher yield, yellowness, lightness, hue, chroma, TPC, punicic, oleic, stearic, triterpene, arachidic, as well as greater degree of unsaturation of fatty acids and conjugated dienes. In contrast, PKO of ‘Wonderful’ and ‘Herskovitz’ are characterized as having high refractive index, total carotenoids, DPPH antioxidant capacity, phytosterol, tocol and several fatty acids in addition to exhibiting lower resistance to oxidation.

5. Conclusions

n-Hexane, petroleum ether and acetone derived PKO of ‘Wonderful’, ‘Acco’ and ‘Herskovitz’ could serve as a good source of bioactive oil. The yield of PKO was cultivar dependent while the extraction solvents employed influenced the quality indices and chemical properties of PKO. In addition, all investigated PKO contained high contents of phenols, punicic acid and possess high radical scavenging activity. These attributes are desirable for fortification and formulation of new or existing products in pharmaceutical, cosmeceutical and food industries. However, the measured oil properties were affected during storage, especially in oil stored at 60°C. As a result, higher levels of conjugated dienes and trienes, *para*-anisidine value and total carotenoids were found in stored PKO in comparison to fresh PKO. In addition, a remarkable reduction in punicic acid and an increase in α- and γ-linolenic acids were also observed. Overall, room temperature storage minimised quality loss.

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Table 1: Colour attributes of pomegranate kernel oil of ‘Wonderful’, ‘Acco’ and ‘Herskovitz’ extracted with three solvents

	Cultivar								
	Wonderful			Acco			Herskovitz		
Attribute	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone
*L**	38.83±2.26^{ab}	41.28±2.23^{a}	28.44±1.17^{d}	37.73±2.75^{ab}	36.76±1.88^{abc}	33.97±1.73^{bcd}	37.32±2.51^{ab}	39.79±3.30^{ab}	30.39±1.43^{cd}
a*	5.03±1.03^{a}	6.31±0.79^{a}	4.04±0.72^{a}	5.60±1.45^{a}	4.71±1.42^{a}	7.41±0.74^{a}	7.05±1.74^{a}	5.57±1.45^{a}	7.93±1.02^{a}
*b**	30.90±4.05^{a}	36.86±4.21^{a}	14.10±1.03^{c}	30.46±4.53^{a}	26.76±3.90^{ab}	25.52±2.48^{abc}	33.29±4.29^{a}	33.92±5.90^{a}	17.65±2.46^{bc}
*C**	31.33±4.16^{ab}	37.41±4.25^{a}	14.72±1.11^{c}	31.12±4.56^{ab}	27.26±4.03^{ab}	26.59±2.55^{abc}	34.10±4.51^{a}	34.43±6.01^{a}	19.38±2.60^{bc}
h°	81.23±0.94^{a}	80.10±0.98^{a}	74.12±2.28^{b}	79.80±3.00^{a}	80.68±2.09^{a}	73.77±0.98^{b}	79.11±1.97^{ab}	81.12±1.64^{a}	65.78±1.74^{c}

Values followed by different letters in the same row are significantly different at 5% level by Duncan Multiple Range Test.

Lightness (*L**), redness (a*), yellowness (*b**), chroma (*C**), hue angle (*h*°).

Table 2: Indices and chemical properties of pomegranate kernel oil of ‘Wonderful’, ‘Acco’ and ‘Herskovitz’ extracted with three solvents

	Cultivar								
	Wonderful			Acco			Herskovitz		
Property	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone
Index									
RI (25°C)	1.5215 ± 0.00^{a}	1.5215 ± 0.00^{a}	1.5215 ± 0.00^{a}	1.5200 ± 0.00^{a}	1.5200 ± 0.00^{a}	1.5200 ± 0.00^{a}	1.5210 ± 0.00^{a}	1.5210 ± 0.00^{a}	1.5210 ± 0.00^{a}
CD (unit)	0.23 ± 0.01^{e}	0.44 ± 0.02^{bc}	0.42 ± 0.02^{bc}	0.52 ± 0.02^{a}	0.43 ± 0.01^{bc}	0.42 ± 0.00^{bc}	0.45 ± 0.02^{b}	0.40 ± 0.00^{c}	0.31 ± 0.01^{d}
CT (unit)	0.79 ± 0.01^{de}	0.80 ± 0.01^{bcd}	0.81 ± 0.00^{a}	0.81 ± 0.00^{ab}	0.78 ± 0.00^{e}	0.80 ± 0.00^{abc}	0.79 ± 0.00^{cde}	0.79 ± 0.00^{cde}	0.80 ± 0.00^{bcd}
p-AV	7.79 ± 2.22^{bc}	5.24 ± 0.94^{cd}	7.81 ± 1.04^{bc}	7.15 ± 0.58^{bcd}	3.94 ± 0.35^{d}	9.71 ± 0.50^{ab}	9.89 ± 0.82^{ab}	7.05 ± 0.44^{bcd}	11.66 ± 1.37^{a}
Chemical									
TPC (mg GAE/g)	0.78 ± 0.35^{d}	0.43 ± 0.00^{d}	4.32 ± 0.35^{b}	5.39 ± 2.32^{b}	4.32 ± 0.35^{b}	6.10 ± 0.35^{ab}	3.61 ± 0.61^{bc}	1.49 ± 0.61^{cd}	8.58 ± 0.35^{a}
TCC$_{440\ nm}$ (g β-carotene/kg)	0.18 ± 0.02^{bc}	0.28 ± 0.01^{a}	0.25 ± 0.01^{a}	0.18 ± 0.04^{bc}	0.11 ± 0.02^{d}	0.17 ± 0.01^{cd}	0.22 ± 0.01^{abc}	0.24 ± 0.02^{ab}	0.29 ± 0.02^{a}
TCC$_{460\ nm}$ (g β-carotene/kg)	0.21 ± 0.00^{c}	0.30 ± 0.00^{a}	0.21 ± 0.00^{c}	0.17 ± 0.10^{d}	0.10 ± 0.00^{f}	0.16 ± 0.01^{e}	0.27 ± 0.00^{b}	0.29 ± 0.01^{a}	0.27 ± 0.00^{b}
DPPH (%RSA)	90.20 ± 0.20^{ab}	89.75 ± 0.04^{b}	90.05 ± 0.06^{ab}	89.83 ± 0.04^{b}	90.74 ± 0.97^{ab}	89.50 ± 0.02^{b}	91.13 ± 0.98^{ab}	90.79 ± 0.60^{ab}	91.60 ± 0.45^{a}

Values followed by different letters in the same row are significantly different at 5% level by Duncan Multiple Range Test.

Refractive index (RI), Conjugated dienes (CD), Conjugated trienes (CT), *para*-Anisidine value (*p*-AV), Total phenolic content (TPC), Total carotenoid content (TCC), Radical scavenging activity (RSA), RSA of Trolox at 0.0500 mmol/L unit = 94.03%.

Table 3: Fatty acid and derivatives, triterpene, tocol and phytosterol compositions (%) of pomegranate kernel oil of ‘Wonderful’, ‘Acco’ and ‘Herskovitz’ extracted with three solvents

	Cultivar								
	Wonderful			Acco			Herskovitz		
Composition (%)	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone
Palmitic (C16:0)	4.12±0.52^{a}	3.49±0.34^{a}	4.14±0.62^{a}	3.69±0.12^{a}	3.68±0.12^{a}	3.94±0.05^{a}	3.90±0.24^{a}	4.08±0.27^{a}	4.45±0.25^{a}
Stearic (C18:0)	2.82±0.43^{a}	2.03±0.23^{b}	2.12±0.29^{ab}	2.73±0.24^{ab}	2.70±0.10^{ab}	2.84±0.04^{a}	2.08±0.14^{ab}	2.20±0.17^{ab}	2.44±0.03^{ab}
Arachidic (C20:0)	0.52±0.06^{a}	0.46±0.05^{a}	0.50±0.08^{a}	0.50±0.00^{a}	0.53±0.06^{a}	0.59±0.00^{a}	0.51±0.02^{a}	0.59±0.00^{a}	0.60±0.06^{a}
∑SFA	7.45±0.02^{a}	5.98±0.63^{a}	6.76±0.99^{a}	6.92±0.35^{a}	6.91±0.28^{a}	7.37±0.10^{a}	6.49±0.40^{a}	6.86±0.45^{a}	7.49±0.22^{a}
Oleic (C18:1)	5.28±0.81^{ac}	3.66±0.42^{c}	4.68±0.87^{ac}	5.54±0.48^{ab}	5.70±0.17^{ab}	5.97±0.00^{a}	4.66±0.10^{ac}	4.70±0.41^{ac}	4.19±0.25^{cb}
Vaccenic (C18:1)	0.86±0.29^{a}	0.46±0.04^{b}	0.55±0.08^{ab}	0.42±0.03^{b}	0.43±0.02^{b}	0.46±0.00^{b}	0.51±0.02^{ab}	0.54±0.00^{ab}	0.59±0.05^{ab}
Goindoic (C20:1)	0.78±0.12^{a}	0.33±0.00^{cd}	0.74±0.14^{a}	0.62±0.02^{abc}	0.44±0.05^{bcd}	0.32±0.01^{cd}	0.49±0.15^{a-d}	0.31±0.07^{d}	0.67±0.03^{ab}
∑MUFA	6.92±1.23^{a}	4.45±0.45^{b}	5.97±1.09^{ab}	6.58±0.53^{ab}	6.57±0.13^{ab}	6.74±0.00^{a}	5.65±0.03^{ab}	5.56±0.34^{ab}	5.44±0.32^{ab}
Linoleic (C18:2)	7.47±0.74^{a}	5.22±0.44^{a}	7.49±1.70^{a}	5.85±0.18^{a}	6.04±0.03^{a}	5.99±0.34^{a}	7.16±0.10^{a}	7.46±0.65^{a}	6.56±0.03^{a}
Punicic (C18:3)	64.72±0.62^{ac}	69.85±1.69^{a}	61.44±3.79^{bc}	66.62±1.80^{ac}	68.93±0.09^{a}	64.70±0.94^{ac}	67.79±0.81^{ab}	67.94±0.97^{ab}	59.90±3.89^{c}
α-Linolenic (C18:3)	3.20±0.22^{ab}	2.55±1.99^{ab}	4.84±0.43^{a}	1.77±1.32^{ab}	0.57±0.03^{b}	3.62±0.24^{ab}	1.76±1.20^{ab}	2.65±0.39^{ab}	3.53±0.21^{ab}
γ-Linolenic (C18:3)	1.51±0.63^{bc}	2.41±0.74^{bc}	4.10±0.06^{a}	1.90±0.04^{bc}	1.62±0.13^{bc}	2.69±0.22^{b}	1.73±0.12^{bc}	1.17±0.25^{c}	2.29±0.40^{bc}
∑PUFA	76.90±0.52^{ab}	80.03±0.59^{a}	77.86±2.58^{ab}	76.14±0.70^{ab}	77.16±0.28^{ab}	77.00±0.13^{ab}	78.44±0.61^{ab}	79.21±0.98^{a}	72.28±4.54^{b}
∑UFA	83.82±1.74^{ab}	84.48±0.14^{a}	83.83±1.49^{ab}	82.72±1.23^{ab}	83.73±0.41^{ab}	83.74±0.12^{ab}	84.09±0.58^{ab}	84.77±1.32^{a}	77.72±4.86^{b}
Others									
Triterpene (squalene)	3.34±1.34^{a}	3.16±0.29^{a}	2.59±0.25^{a}	3.11±0.49^{a}	2.87±0.14^{a}	2.56±0.05^{a}	1.97±0.12^{a}	1.77±0.50^{a}	3.14±0.81^{a}
Tocol (γ-tocopherol)	2.11±0.38^{b}	2.57±0.13^{b}	3.23±0.21^{b}	3.52±0.64^{b}	3.34±0.23^{b}	3.58±0.03^{b}	3.83±0.39^{b}	3.72±0.99^{b}	7.27±2.09^{a}
Phytosterol (γ-sitosterol)	2.44±0.32^{b}	3.10±0.27^{b}	3.03±0.67^{b}	3.02±0.31^{b}	2.51±0.27^{b}	2.16±0.09^{b}	3.00±0.48^{b}	2.76±0.69^{b}	5.11±1.23^{a}
PUFA/MUFA	11.46±1.96^{b}	18.20±1.99^{a}	13.58±2.92^{ab}	11.64±0.83^{b}	11.75±0.19^{b}	11.42±0.03^{b}	13.87±0.17^{ab}	14.30±0.70^{ab}	13.28±0.05^{b}
SFA/MUFA	1.11±0.20^{ab}	1.34±0.00^{ab}	1.14±0.04^{ab}	1.05±0.03^{b}	1.05±0.02^{b}	1.09±0.00^{ab}	1.15±0.08^{ab}	1.23±0.00^{ab}	1.38±0.12^{a}
SFA/PUFA	0.10±0.00^{ab}	0.07±0.01^{b}	0.09±0.02^{ab}	0.09±0.00^{ab}	0.09±0.00^{ab}	0.10±0.00^{ab}	0.08±0.00^{ab}	0.09±0.00^{ab}	0.10±0.01^{a}
SFA/UFA	0.09±0.00^{ab}	0.07±0.01^{b}	0.08±0.01^{ab}	0.08±0.00^{ab}	0.08±0.00^{ab}	0.09±0.00^{ab}	0.08±0.00^{ab}	0.08±0.00^{ab}	0.10±0.01^{a}
IA	0.05±0.00^{ab}	0.04±0.00^{b}	0.04±0.01^{ab}	0.04±0.00^{ab}	0.04±0.00^{ab}	0.05±0.00^{ab}	0.04±0.00^{ab}	0.04±0.00^{ab}	0.05±0.01^{a}
IT	0.03±0.00^{ab}	0.02±0.00^{b}	0.02±0.00^{ab}	0.02±0.00^{ab}	0.02±0.00^{ab}	0.03±0.00^{ab}	0.02±0.00^{ab}	0.02±0.00^{ab}	0.03±0.00^{a}

Values followed by different letters in the same row are significantly different at 5% level by Duncan Multiple Range Test.
Saturated fatty acid (SFA), Monounsaturated fatty acid (MUFA), Polyunsaturated fatty acid (PUFA), Summation of (∑), Unsaturated fatty acid (UFA), Index of atherogenicity (IA), Index of thrombogenicity (IT).

Table 4: Changes in indices of pomegranate kernel oil of ‘Wonderful’, ‘Acco’ and ‘Herskovitz’ subjected to different storage temperatures and duration

		Cultivar								
		Wonderful			Acco			Herskovitz		
Property	Storage (days)	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone
CD (unit)	Day 0	0.23±0.01^{o}	0.44±0.02^{m}	0.42±0.02^{m}	0.52±0.02^{l}	0.43±0.01^{m}	0.42±0.00^{m}	0.45±0.02^{m}	0.40±0.00^{m}	0.31±0.01^{n}
	SH 10	2.11±0.02$^{b\text{-}h}$	2.10±0.02$^{b\text{-}h}$	2.09±0.01$^{c\text{-}h}$	1.98±0.02^{jk}	2.02±0.02^{ji}	2.10±0.03$^{b\text{-}l}$	1.95±0.01^{k}	2.14±0.04$^{a\text{-}f}$	2.13±0.03$^{a\text{-}f}$
	SH 20	2.11±0.02$^{b\text{-}h}$	2.11±0.03$^{b\text{-}g}$	2.11±0.02$^{b\text{-}h}$	2.10±0.02$^{a\text{-}f}$	2.09±0.02$^{c\text{-}h}$	2.04±0.01$^{g\text{-}j}$	2.12±0.04$^{a\text{-}f}$	2.04±0.02^{hij}	2.13±0.02$^{a\text{-}f}$
	SH 30	2.13±0.02$^{a\text{-}f}$	2.18±0.02^{ab}	2.13±0.02$^{a\text{-}f}$	2.13±0.01$^{a\text{-}f}$	2.10±0.02$^{b\text{-}h}$	2.14±0.02$^{a\text{-}e}$	2.15±0.00$^{a\text{-}d}$	2.17±0.02^{abc}	2.07±0.01$^{e\text{-}i}$
	OV 10	2.12±0.01$^{a\text{-}g}$	2.14±0.03$^{a\text{-}e}$	2.12±0.03$^{a\text{-}g}$	2.10±0.01$^{b\text{-}h}$	2.11±0.03$^{b\text{-}h}$	2.09±0.02$^{d\text{-}i}$	2.14±0.02$^{a\text{-}f}$	2.11±0.02$^{b\text{-}h}$	2.15±0.02$^{a\text{-}d}$
	OV 20	2.15±0.03$^{a\text{-}d}$	2.12±0.02$^{a\text{-}f}$	2.15±0.04$^{a\text{-}d}$	2.16±0.02$^{a\text{-}d}$	2.07±0.01$^{f\text{-}i}$	2.13±0.02$^{a\text{-}f}$	2.12±0.03$^{a\text{-}f}$	2.16±0.03$^{a\text{-}d}$	2.16±0.03$^{a\text{-}d}$
	OV 30	2.15±0.02$^{a\text{-}d}$	2.17±0.01^{abc}	2.17±0.03^{abc}	2.14±0.03$^{a\text{-}d}$	2.15±0.02$^{a\text{-}d}$	2.19±0.02^{a}	2.16±0.01$^{a\text{-}d}$	2.16±0.01^{abc}	2.16±0.03^{abc}
CT (unit)	Day 0	0.79±0.01^{kl}	0.80±0.01^{jk}	0.81±0.00^{j}	0.81±0.00^{j}	0.78±0.00^{l}	0.80±0.00^{jk}	0.79±0.00^{kl}	0.79±0.00^{kl}	0.80±0.00^{jk}
	SH 10	1.76±0.00^{ghi}	1.75±0.00^{hi}	1.75±0.00^{ghi}	1.76±0.00^{ghi}	1.76±0.01$^{f\text{-}i}$	1.75±0.00^{hi}	1.76±0.00^{ghi}	1.76±0.00^{ghi}	1.76±0.01$^{f\text{-}i}$
	SH 20	1.75±0.00^{ghi}	1.76±0.01^{ghi}	1.76±0.00$^{f\text{-}i}$	1.75±0.00^{hi}	1.76±0.00$^{f\text{-}i}$	1.76±0.00^{ghi}	1.77±0.01^{fgh}	1.76±0.01^{fgh}	1.76±0.00^{ghi}
	SH 30	1.78±0.00^{cde}	1.78±0.00^{cde}	1.79±0.00$^{b\text{-}e}$	1.78±0.00^{ef}	1.78±0.00^{de}	1.79±0.01$^{a\text{-}e}$	1.78±0.01^{cde}	1.79±0.00$^{b\text{-}e}$	1.78±0.00^{cde}
	OV 10	1.76±0.00^{ghi}	1.76±0.01^{ghi}	1.76±0.01$^{f\text{-}i}$	1.76±0.00^{ghi}	1.75±0.00^{i}	1.76±0.00^{ghi}	1.75±0.00^{ghi}	1.76±0.01^{ghi}	1.77±0.00^{fg}
	OV 20	1.76±0.01$^{f\text{-}i}$	1.76±0.00$^{f\text{-}i}$	1.76±0.01$^{f\text{-}i}$	1.76±0.00^{ghi}	1.75±0.00^{ghi}	1.76±0.01^{ghi}	1.76±0.01^{ghi}	1.76±0.00$^{f\text{-}i}$	1.76±0.00$^{f\text{-}i}$
	OV 30	1.80±0.00^{ab}	1.80±0.00^{abc}	1.79±0.00$^{a\text{-}d}$	1.79±0.01$^{a\text{-}d}$	1.79±0.00$^{a\text{-}d}$	1.80±0.01^{ab}	1.80±0.00^{a}	1.79±0.00$^{a\text{-}d}$	1.80±0.00$^{a\text{-}d}$
p-AV	Day 0	7.79±2.22^{rst}	5.24±0.94st	7.81±1.04^{rst}	7.15±0.58^{rst}	3.94±0.35^{t}	9.71±0.50$^{q\text{-}t}$	9.89±0.82$^{q\text{-}t}$	7.05±0.44^{rst}	11.67±1.37$^{q\text{-}t}$
	SH 10	13.96±0.22$^{p\text{-}s}$	9.85±0.28$^{q\text{-}t}$	10.96±0.37$^{q\text{-}t}$	6.78±0.18^{rst}	6.63±0.22^{rst}	12.55±0.30$^{p\text{-}t}$	11.17±0.46$^{q\text{-}t}$	10.14±0.17$^{q\text{-}t}$	12.65±0.31$^{p\text{-}t}$
	SH 20	18.42±0.05^{opq}	12.83±0.24$^{p\text{-}t}$	13.41±0.21$^{p\text{-}s}$	9.50±1.96$^{q\text{-}t}$	6.74±0.32^{rst}	13.00±0.59$^{p\text{-}t}$	13.77±0.16$^{p\text{-}s}$	12.16±0.32$^{p\text{-}t}$	18.65±0.69^{opq}
	SH 30	27.90±0.24^{mn}	15.81±0.72^{pqr}	14.34±0.34$^{p\text{-}s}$	11.11±0.41$^{q\text{-}t}$	25.71±0.46^{mno}	27.13±0.25^{mn}	17.35±0.63^{pq}	31.28±0.10^{m}	21.06±0.26^{nop}
	OV 10	104.04±1.88^{gh}	77.38±3.35^{j}	72.17±2.16^{j}	50.57±0.11^{l}	59.55±0.14^{k}	54.96±0.13^{kl}	71.20±0.42^{j}	98.47±9.26^{h}	56.55±0.45^{kl}
	OV 20	118.59±0.38^{ef}	163.91±1.25^{ac}	110.90±0.78^{fg}	113.71±0.44^{f}	90.57±0.41^{i}	96.78±1.55^{hi}	167.77±3.35^{ab}	111.99±0.31^{f}	123.91±1.62^{e}
	OV 30	145.66±3.27^{d}	171.07±1.29^{a}	148.97±9.20^{d}	162.70±1.67^{abc}	166.69±0.72^{ab}	165.43±0.80^{ab}	170.57±12.88^{a}	156.64±4.44^{c}	159.46±4.53^{cb}

For each property, values followed by different letters, regardless of the row and column, are significantly different at 5% level by Duncan Multiple Range Test.

Conjugated dienes (CD), Conjugated trienes (CT), *para*-Anisidine value (*p*-AV).

Storage refers to storage temperature & duration (days), shelf stored at 25°C (SH), oven stored at 60°C (OV).

Table 5: Changes in chemical properties of pomegranate kernel oil of 'Wonderful', 'Acco' and 'Herskovitz' subjected to different storage temperatures and duration

		Cultivar								
		Wonderful			Acco			Herskovitz		
Property	Storage (days)	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone
$TCC_{440\ nm}$ (g β-Carotene /kg)	Day 0	$0.18\pm0.02^{g-n}$	$0.28\pm0.01^{e-i}$	$0.25\pm0.01^{e-j}$	$0.18\pm0.04^{g-n}$	$0.11\pm0.02^{i-n}$	$0.17\pm0.01^{g-n}$	$0.22\pm0.01^{e-n}$	$0.24\pm0.02^{e-m}$	$0.29\pm0.02^{e-h}$
	SH 10	$0.22\pm0.04^{e-n}$	0.06 ± 0.03^{mn}	$0.07\pm0.00^{k-n}$	$0.12\pm0.01^{h-n}$	$0.17\pm0.07^{g-n}$	$0.33\pm0.03^{d-g}$	$0.13\pm0.04^{h-n}$	$0.08\pm0.01^{j-n}$	$0.17\pm0.03^{g-n}$
	SH 20	$0.07\pm0.02^{l-n}$	0.06 ± 0.00^{n}	0.06 ± 0.01^{n}	$0.10\pm0.03^{j-n}$	$0.10\pm0.02^{j-n}$	$0.17\pm0.03^{g-n}$	$0.08\pm0.01^{j-n}$	$0.13\pm0.03^{h-n}$	$0.18\pm0.02^{g-n}$
	SH 30	$0.18\pm0.03^{g-n}$	$0.15\pm0.03^{h-n}$	$0.14\pm0.02^{h-n}$	$0.09\pm0.01^{j-n}$	$0.08\pm0.01^{j-n}$	$0.12\pm0.01^{h-n}$	$0.25\pm0.03^{e-k}$	$0.15\pm0.01^{h-n}$	$0.15\pm0.02^{h-n}$
	OV 10	$0.09\pm0.04^{j-n}$	$0.11\pm0.04^{i-n}$	$0.10\pm0.01^{j-n}$	$0.09\pm0.02^{j-n}$	$0.11\pm0.01^{i-n}$	$0.14\pm0.03^{h-n}$	$0.14\pm0.03^{h-n}$	$0.15\pm0.01^{h-n}$	$0.17\pm0.02^{g-n}$
	OV 20	$0.24\pm0.02^{e-m}$	0.35 ± 0.23^{def}	$0.19\pm0.03^{f-n}$	$0.23\pm0.06^{e-n}$	$0.17\pm0.03^{g-n}$	0.36 ± 0.06^{de}	0.54 ± 0.06^{b}	$0.17\pm0.04^{g-n}$	$0.24\pm0.03^{e-l}$
	OV 30	0.80 ± 0.04^{a}	0.56 ± 0.06^{b}	0.49 ± 0.06^{bcd}	0.45 ± 0.10^{bcd}	0.55 ± 0.13^{b}	0.52 ± 0.07^{bc}	0.88 ± 0.04^{a}	0.52 ± 0.06^{bc}	0.38 ± 0.07^{cde}
$TCC_{460\ nm}$ (g β-Carotene /kg)	Day 0	$0.21\pm0.00^{g-k}$	$0.30\pm0.00^{e-h}$	$0.21\pm0.00^{g-k}$	$0.17\pm0.00^{g-l}$	0.10 ± 0.00^{kl}	$0.16\pm0.01^{h-l}$	$0.27\pm0.00^{f-j}$	$0.29\pm0.01^{e-i}$	$0.27\pm0.00^{f-j}$
	SH 10	$0.17\pm0.03^{g-l}$	0.05 ± 0.02^{l}	0.07 ± 0.00^{kl}	$0.15\pm0.01^{i-l}$	0.13 ± 0.05^{jkl}	$0.27\pm0.02^{f-j}$	0.12 ± 0.04^{jkl}	0.09 ± 0.01^{kl}	0.13 ± 0.02^{jkl}
	SH 20	0.06 ± 0.01^{l}	0.04 ± 0.00^{l}	0.06 ± 0.00^{l}	0.11 ± 0.04^{kl}	0.09 ± 0.02^{kl}	0.13 ± 0.02^{jkl}	0.07 ± 0.01^{kl}	0.10 ± 0.02^{kl}	0.14 ± 0.02^{jkl}
	SH 30	$0.15\pm0.03^{i-l}$	0.13 ± 0.03^{jkl}	0.14 ± 0.02^{jkl}	0.09 ± 0.01^{kl}	0.06 ± 0.01^{kl}	0.09 ± 0.01^{kl}	$0.21\pm0.03^{g-k}$	0.13 ± 0.01^{jkl}	0.12 ± 0.02^{jkl}
	OV 10	0.07 ± 0.03^{kl}	0.11 ± 0.06^{kl}	0.13 ± 0.00^{jkl}	0.06 ± 0.01^{kl}	0.05 ± 0.02^{l}	0.11 ± 0.03^{kl}	0.11 ± 0.03^{kl}	$0.18\pm0.02^{g-l}$	$0.19\pm0.02^{g-l}$
	OV 20	$0.19\pm0.02^{g-l}$	$0.32\pm0.21^{d-g}$	0.14 ± 0.02^{jkl}	$0.18\pm0.05^{g-l}$	0.13 ± 0.03^{jkl}	$0.30\pm0.06^{e-h}$	0.44 ± 0.06^{cd}	0.14 ± 0.03^{jkl}	$0.19\pm0.03^{g-l}$
	OV 30	0.74 ± 0.04^{a}	0.57 ± 0.05^{b}	0.48 ± 0.05^{bc}	$0.39\pm0.08^{c-f}$	0.46 ± 0.11^{bc}	0.41 ± 0.05^{cde}	0.72 ± 0.03^{a}	0.45 ± 0.06^{bc}	$0.32\pm0.06^{d-g}$
DPPH (% RSA)	Day 0	90.20 ± 0.20^{op}	89.75 ± 0.04^{op}	90.05 ± 0.06^{op}	89.83 ± 0.04^{op}	90.74 ± 0.97^{op}	89.50 ± 0.02^{p}	91.13 ± 0.98^{op}	90.79 ± 0.60^{op}	91.60 ± 0.45^{no}
	SH 10	97.62 ± 0.38^{bc}	$94.92\pm0.37^{f-m}$	$95.03\pm0.49^{f-m}$	$95.82\pm0.52^{c-k}$	$96.94\pm0.78^{c-f}$	$95.17\pm0.17^{f-l}$	$96.23\pm0.37^{c-j}$	$96.08\pm0.24^{c-k}$	$95.55\pm0.32^{c-k}$
	SH 20	99.48 ± 0.38^{a}	97.56 ± 0.38^{bc}	$95.89\pm0.47^{c-k}$	$95.56\pm0.41^{c-k}$	$94.51\pm0.25^{h-m}$	$95.39\pm0.45^{d-k}$	$95.66\pm0.11^{c-k}$	$95.56\pm0.14^{c-k}$	$95.41\pm0.65^{d-k}$
	SH 30	$94.91\pm0.52^{f-m}$	94.05 ± 0.21^{klm}	$94.44\pm0.40^{i-m}$	$95.67\pm0.89^{c-k}$	$95.01\pm0.34^{f-m}$	92.99 ± 0.07^{mn}	$94.51\pm0.31^{h-m}$	$94.47\pm0.15^{h-m}$	93.23 ± 0.10^{lmn}
	OV 10	$96.62\pm1.95^{c-h}$	97.40 ± 1.24^{bcd}	$94.92\pm0.72^{f-m}$	$95.71\pm0.99^{c-k}$	$96.50\pm0.78^{c-i}$	$95.43\pm1.01^{d-k}$	$96.71\pm0.77^{c-g}$	97.62 ± 0.62^{bc}	$95.27\pm0.24^{e-l}$
	OV 20	$97.35\pm0.96^{c-e}$	98.27 ± 0.75^{ab}	$95.82\pm0.76^{c-k}$	$95.80\pm0.80^{c-k}$	$95.95\pm0.32^{c-k}$	$95.94\pm0.28^{c-k}$	$95.16\pm0.13^{f-l}$	$94.90\pm0.61^{f-m}$	93.94 ± 0.36^{klm}
	OV 30	$94.38\pm0.13^{i-m}$	$96.04\pm1.09^{c-k}$	93.94 ± 0.42^{klm}	$95.14\pm0.72^{f-l}$	$95.02\pm0.15^{f-m}$	$94.33\pm0.40^{j-m}$	$96.02\pm0.59^{c-k}$	$94.64\pm0.09^{g-m}$	$95.27\pm0.43^{e-l}$

For each property, values followed by different letters, regardless of the row and column, are significantly different at 5% level by Duncan Multiple Range Test.

Total carotenoid content (TCC), Radical scavenging activity (RSA)

Storage refers to storage temperature & duration (days), shelf stored at 25°C (SH), oven stored at 60°C (OV).

Table 6: Changes in fatty acids, tocol and phytosterol in pomegranate kernel oil subjected to different storage temperatures and duration

Property	Storage (days)	Cultivar								
		Wonderful			Acco			Herskovitz		
		Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone
Punicic (C18:3)	Day 0	$64.72\pm0.62^{a-i}$	$69.85\pm1.69^{a-d}$	$61.44\pm3.79^{a-k}$	$66.62\pm1.80^{a-i}$	$68.93\pm0.09^{a-g}$	$64.70\pm0.94^{a-i}$	$67.79\pm0.81^{a-h}$	$67.94\pm0.97^{a-h}$	$59.90\pm3.89^{a-m}$
	SH 10	72.56 ± 0.49^{a}	$54.56\pm17.16^{f-o}$	70.98 ± 1.32^{abc}	$54.66\pm1.22^{e-o}$	70.92 ± 0.13^{abc}	$66.50\pm1.49^{a-i}$	$67.28\pm0.54^{a-h}$	$65.73\pm7.68^{a-i}$	$68.48\pm0.48^{a-h}$
	SH 20	$70.13\pm2.01^{a-d}$	$65.66\pm6.90^{a-i}$	71.68 ± 1.57^{ab}	$55.08\pm0.53^{d-o}$	$54.17\pm17.07^{f-o}$	$67.20\pm1.37^{a-h}$	$62.84\pm11.70^{a-j}$	$60.53\pm10.43^{a-l}$	$64.04\pm4.69^{a-i}$
	SH 30	$66.87\pm1.53^{a-h}$	$66.14\pm0.32^{a-i}$	$68.33\pm1.34^{a-h}$	$69.29\pm2.79^{a-f}$	$65.73\pm1.20^{a-i}$	$66.89\pm1.25^{a-h}$	$69.74\pm0.18^{a-e}$	$64.44\pm0.29^{a-i}$	$66.52\pm0.89^{a-i}$
	OV 10	45.13 ± 2.58^{mno}	$51.76\pm0.78^{i-o}$	$47.67\pm7.01^{k-o}$	$55.02\pm5.69^{d-o}$	$64.15\pm0.30^{a-i}$	$58.64\pm0.13^{a-m}$	43.52 ± 0.10^{no}	$63.79\pm0.17^{a-i}$	$56.11\pm0.57^{c-n}$
	OV 20	43.51 ± 0.93^{no}	$54.14\pm0.12^{g-o}$	$48.40\pm0.57^{j-o}$	$51.69\pm3.37^{i-o}$	$60.31\pm0.84^{a-l}$	$61.40\pm2.13^{a-k}$	$58.99\pm0.70^{a-m}$	$57.74\pm1.51^{a-n}$	$56.82\pm0.93^{b-n}$
	OV 30	41.11 ± 0.87^{o}	$53.37\pm1.34^{h-o}$	$46.00\pm1.68^{l-o}$	$56.94\pm1.28^{b-n}$	$60.41\pm0.83^{a-l}$	$54.72\pm1.08^{e-n}$	$57.85\pm0.43^{a-n}$	$58.82\pm0.75^{a-m}$	$47.07\pm1.17^{k-n}$
α-Linolenic (C18:3)	Day 0	$3.20\pm0.22^{g-j}$	2.55 ± 1.99^{hij}	$4.84\pm0.43^{d-j}$	1.77 ± 1.32^{ij}	0.57 ± 0.03^{j}	$3.62\pm0.24^{f-j}$	1.76 ± 1.20^{ij}	2.65 ± 0.39^{hij}	$3.53\pm0.21^{g-j}$
	SH 10	1.90 ± 1.49^{ij}	$7.28\pm4.31^{b-j}$	2.51 ± 2.12^{hij}	$12.18\pm0.35^{a-f}$	2.23 ± 0.02^{hij}	$3.18\pm0.47^{g-j}$	$3.87\pm0.07^{f-j}$	$5.85\pm5.50^{d-j}$	$3.93\pm0.14^{f-j}$
	SH 20	$4.26\pm0.39^{e-j}$	$6.76\pm4.36^{c-j}$	2.19 ± 1.85^{hij}	15.34 ± 1.92^{ab}	$12.80\pm11.19^{a-e}$	$3.48\pm0.64^{g-j}$	$8.31\pm7.91^{b-j}$	$7.12\pm4.41^{b-j}$	$7.42\pm2.45^{b-j}$
	SH 30	$5.52\pm0.14^{d-j}$	$4.45\pm0.05^{e-j}$	$4.27\pm0.05^{e-j}$	1.77 ± 1.25^{ij}	$3.95\pm0.01^{f-j}$	$3.87\pm0.05^{f-j}$	$3.42\pm0.03^{g-j}$	$5.82\pm0.32^{d-j}$	$4.76\pm0.55^{d-j}$
	OV 10	$7.98\pm3.50^{b-j}$	$9.92\pm0.16^{a-i}$	14.83 ± 4.52^{abc}	$9.03\pm3.36^{a-j}$	$7.05\pm0.13^{b-j}$	$8.15\pm0.19^{b-j}$	15.35 ± 0.11^{ab}	$5.76\pm0.25^{d-j}$	$9.15\pm0.01^{a-j}$
	OV 20	$13.29\pm1.05^{a-d}$	$10.27\pm0.72^{a-i}$	$10.34\pm1.24^{a-i}$	$10.71\pm3.53^{a-h}$	$6.31\pm0.37^{c-j}$	$6.43\pm0.26^{c-j}$	$8.63\pm0.21^{b-j}$	$6.52\pm0.78^{c-j}$	$9.90\pm0.26^{a-i}$
	OV 30	17.10 ± 0.80^{a}	$11.56\pm0.20^{a-g}$	$12.73\pm1.91^{a-e}$	$9.30\pm0.00^{a-i}$	$7.49\pm0.16^{b-j}$	$10.17\pm0.46^{a-i}$	$10.10\pm0.15^{a-i}$	$8.80\pm0.37^{a-j}$	$13.26\pm0.66^{a-d}$
γ-Linolenic (C18:3)	Day 0	1.51 ± 0.63^{opq}	$2.41\pm0.74^{n-q}$	$4.10\pm0.06^{j-q}$	1.90 ± 0.04^{opq}	1.62 ± 0.13^{opq}	$2.69\pm0.22^{m-q}$	1.73 ± 0.12^{opq}	1.17 ± 0.25^{pq}	$2.29\pm0.40^{n-q}$
	SH 10	1.54 ± 1.13^{opq}	$9.30\pm7.41^{e-k}$	1.77 ± 1.42^{opq}	$3.27\pm0.14^{l-q}$	0.41 ± 0.01^{q}	1.68 ± 1.41^{opq}	$3.32\pm0.20^{l-q}$	$2.57\pm0.60^{n-q}$	0.27 ± 0.01^{q}
	SH 20	1.99 ± 1.57^{opq}	$2.50\pm1.34^{n-q}$	$3.37\pm0.06^{l-q}$	$2.80\pm0.37^{m-q}$	$4.63\pm3.46^{h-q}$	$2.63\pm0.85^{n-q}$	$3.39\pm1.22^{l-q}$	$6.80\pm5.13^{e-p}$	$2.57\pm0.97^{n-q}$
	SH 30	$2.43\pm1.79^{n-q}$	$3.58\pm0.30^{k-q}$	$3.61\pm0.03^{k-q}$	$2.46\pm0.27^{n-q}$	$2.72\pm0.01^{m-q}$	$2.75\pm0.07^{m-q}$	$2.57\pm0.16^{n-q}$	$5.55\pm0.07^{g-q}$	$4.37\pm0.72^{i-q}$
	OV 10	$11.58\pm6.39^{c-f}$	$12.36\pm0.26^{b-e}$	$9.93\pm3.74^{e-i}$	$5.66\pm1.05^{g-q}$	$7.30\pm0.03^{e-o}$	$8.44\pm0.78^{e-m}$	16.50 ± 0.03^{abc}	$5.89\pm0.02^{f-q}$	$10.24\pm0.10^{e-h}$
	OV 20	20.87 ± 0.47^{a}	$11.25\pm0.16^{c-g}$	17.13 ± 0.25^{ab}	$8.60\pm0.78^{e-l}$	$8.06\pm0.31^{e-n}$	$7.04\pm0.45^{e-o}$	$8.84\pm0.15^{e-l}$	$8.93\pm0.69^{e-l}$	11.79 ± 0.57^{cde}
	OV 30	18.60 ± 0.91^{a}	$11.56\pm0.34^{c-f}$	17.96 ± 0.31^{a}	$8.77\pm0.22^{e-l}$	$7.23\pm0.21^{e-o}$	$10.81\pm0.38^{d-g}$	$9.76\pm0.25^{e-j}$	$8.96\pm0.27^{e-l}$	$15.87\pm0.72^{a-d}$

For each property, values followed by different letters, regardless of the row and column, are significantly different at 5% level by Duncan Multiple Range Test.

Storage refers to storage temperature & duration (days), Shelf stored at 25°C (SH), Oven stored at 60°C (OV).

Table 6 (continues)

Table 6: Changes in fatty acids, tocol and phytosterol in pomegranate kernel oil subjected to different storage temperatures and duration

		Cultivar								
		Wonderful			Acco			Herskovitz		
Property	Storage (days)	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone
Tocol (γ-tocopherol)	Day 0	2.11±0.38^{e-k}	2.57±0.13^{c-g}	3.23±0.21^{b-e}	3.52±0.64^{bc}	3.34±0.23^{bcd}	3.58±0.03^{bc}	3.83±0.39^{b}	3.72±0.99^{bc}	7.27±2.09^{a}
	SH 10	1.32±0.13^{g-l}	2.09±0.08^{e-k}	1.77±0.27^{f-l}	1.43±0.07^{f-l}	1.28±0.05^{h-l}	1.53±0.19^{f-l}	1.18±0.09^{jkl}	1.61±0.00^{f-l}	1.84±0.03^{f-l}
	SH 20	1.55±0.29^{f-l}	1.53±0.06^{f-l}	1.92±0.08^{f-l}	1.38±0.15^{g-l}	1.67±0.07^{f-l}	1.46±0.10^{f-l}	1.20±0.10^{jkl}	0.98±0.16^{jkl}	2.56±0.43^{c-h}
	SH 30	1.24±0.06^{i-l}	1.38±0.28^{g-l}	1.89±0.18^{f-l}	1.27±0.13^{h-l}	2.71±0.54^{b-f}	2.71±0.24^{b-f}	1.14±0.03^{jkl}	1.07±0.04^{jkl}	2.53±0.81^{c-i}
	OV 10	2.21±0.25^{d-j}	1.35±0.10^{g-l}	1.90±0.45^{f-l}	1.47±0.12^{f-l}	1.27±0.24^{h-l}	1.75±0.17^{f-l}	1.49±0.13^{f-l}	1.75±0.02^{f-l}	1.91±0.02^{f-l}
	OV 20	0.77±0.09^{l}	1.07±0.09^{jkl}	1.39±0.12^{g-l}	1.20±0.08^{jkl}	1.08±0.04^{jkl}	1.52±0.03^{f-l}	1.91±0.04^{f-l}	1.11±0.03^{jkl}	1.41±0.12^{g-l}
	OV 30	1.14±0.08^{jkl}	0.85±0.19^{kl}	1.00±0.16^{jkl}	0.95±0.16^{jkl}	0.84±0.04^{kl}	0.75±0.04^{l}	0.89±0.15^{kl}	0.96±0.16^{jkl}	1.17±0.31^{jkl}
Phyto-Sterol (γ-sitosterol)	Day 0	2.44±0.32^{bcd}	3.10±0.27^{b}	3.03±0.67^{b}	3.02±0.31^{b}	2.51±0.27^{bcd}	2.16±0.09^{cde}	3.00±0.48^{b}	2.76±0.69^{bc}	5.11±1.23^{a}
	SH 10	1.25±0.05^{f-n}	1.80±0.33^{d-g}	0.95±0.04^{g-n}	0.47±0.03^{mn}	0.44±0.10^{mn}	0.36±0.02^{n}	0.70±0.04^{j-n}	0.67±0.01^{j-n}	0.68±0.05^{j-n}
	SH 20	1.30±0.06^{f-m}	1.49±0.09^{e-k}	1.20±0.17^{f-n}	0.51±0.02^{mn}	0.81±0.05^{i-n}	0.37±0.06^{n}	0.78±0.05^{i-n}	0.64±0.04^{j-n}	1.18±0.09^{f-n}
	SH 30	0.75±0.02^{i-n}	0.95±0.28^{g-n}	0.91±0.01^{h-n}	0.51±0.05^{mn}	1.13±0.26^{f-n}	0.92±0.16^{g-n}	0.55±0.05^{l-n}	0.49±0.03^{mn}	0.78±0.06^{i-n}
	OV 10	1.93±0.39^{def}	1.77±0.03^{e-h}	1.45±0.53^{e-l}	1.30±0.07^{f-m}	0.60±0.02^{k-n}	0.80±0.01^{i-n}	1.08±0.11^{f-n}	0.97±0.01^{g-n}	0.71±0.03^{i-n}
	OV 20	1.04±0.18^{g-n}	1.60±0.07^{e-i}	1.32±0.10^{e-m}	1.22±0.04^{f-n}	0.68±0.16^{j-n}	0.86±0.04^{i-n}	1.53±0.23^{e-j}	0.86±0.04^{i-n}	0.79±0.10^{i-n}
	OV 30	0.86±0.22^{i-n}	0.78±0.16^{i-n}	0.62±0.08^{k-n}	0.71±0.06^{i-n}	0.51±0.07^{mn}	0.43±0.04^{mn}	0.69±0.19^{j-n}	0.62±0.10^{k-n}	0.61±0.10^{k-n}

For each property, values followed by different letters, regardless of the row and column, are significantly different at 5% level by Duncan Multiple Range Test.

Storage refers to storage temperature & duration (days), Shelf stored at 25°C (SH), Oven stored at 60°C (OV).

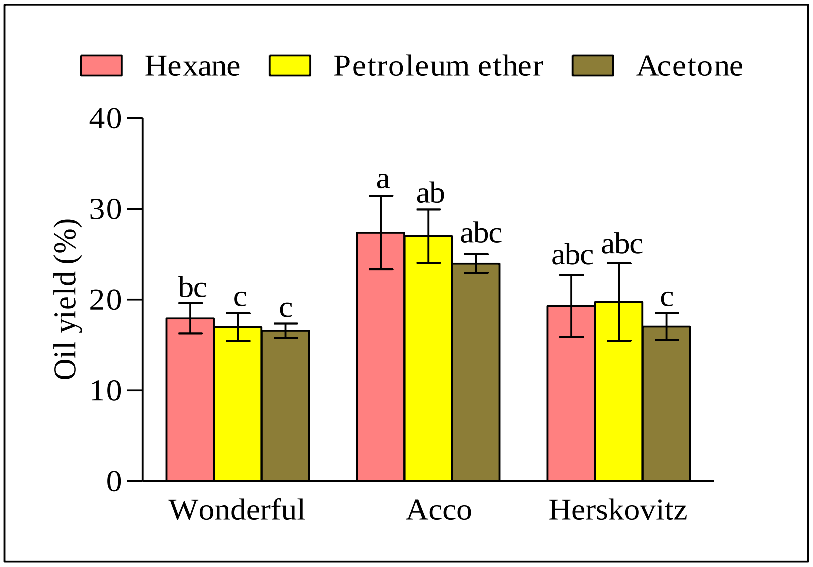

Fig. 1. Oil quantity extracted from pomegranate kernel of Wonderful, Acco and Herskovitz cultivars using different extraction solvents

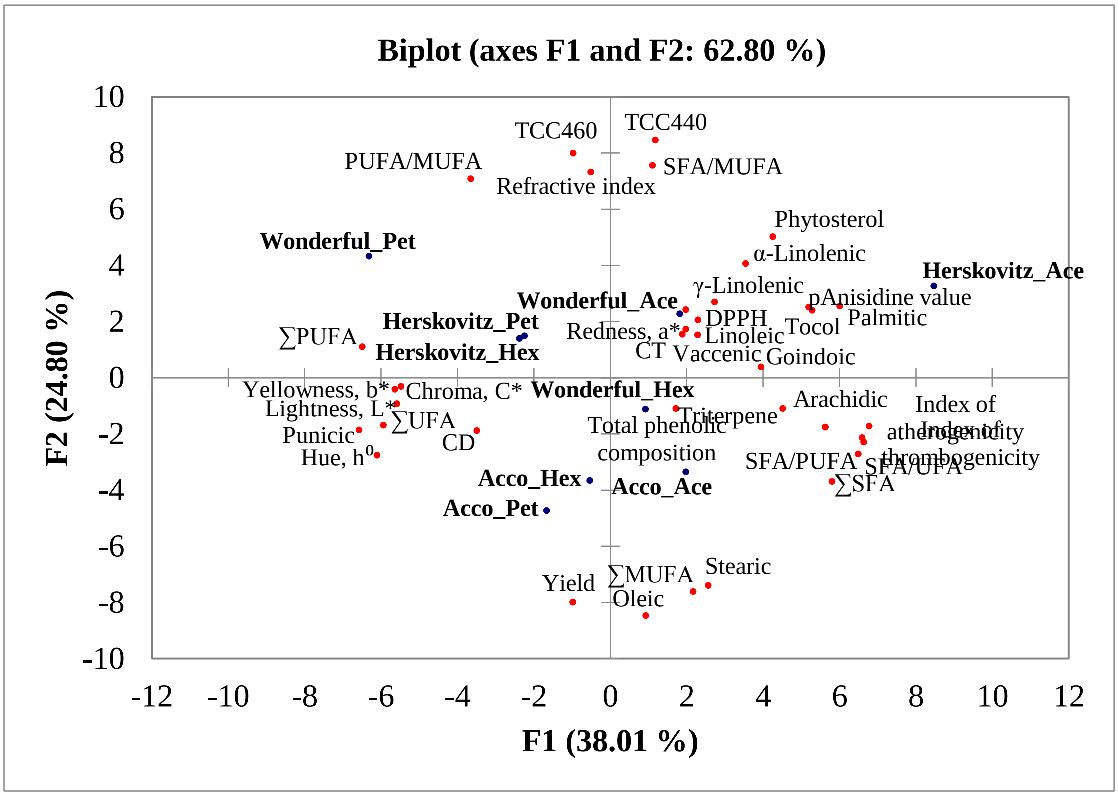

Fig. 2. Principal Component Analysis of F1 and F2 factors showing dispersion of pomegranate fruit cultivars based on measured kernel oil properties

n-hexane (Hex), Petroleum ether (Pet), Acetone (Ace), Conjugated dienes (CD), Conjugated trienes (CT), Total carotenoid content (TCC) wavelength (440 and 460 nm), DPPH radical scavenging activity (DPPH).

Chapter 6

General discussion and conclusions

GENERAL DISCUSSION AND CONCLUSIONS

1. Introduction

Pomegranate has gained extensive applications in several cultures across the globe for its nutritional and medicinal properties (Seeram *et al.*, 2006; Opara *et al.*, 2009). However, the extensive use of pomegranate fruit in South Africa is limited to its juice production. This therefore renders other pomegranate fruit co-products (kernel and oil constituent) with sufficient potential for value-addition as waste during processing (Modaresi *et al*., 2011; De Melo *et al*., 2014). Also, knowledge of the physico-chemical and textural properties of pomegranate fruit relevant to nutrition and processing remains critical. Presently, the South African pomegranate industry, plagued with a high incidence of postharvest losses (Fawole & Opara, 2013a), is also challenged by important issues that govern the processing of pomegranate fruit. In particular, how to classify pomegranate cultivars based on their potential as source of raw material for health-promoting compounds is currently unavailable. In addition, information on how pomegranate cultivar and fruit properties influence prospect for value-addition, nutrition and the ease of processing is also lacking.

Based on the challenges confronting the South African pomegranate sector, which also have implications for the global industry, the objectives of this study were to (a) evaluate some selected physical and textural properties of pomegranate whole fruit, arils and kernels; with relevance to processing, (b) investigate the proximate and mineral compositions of pomegranate kernels and the quality attributes, functional properties and chemical compositions of pomegranate oil; also with emphasis on processing and nutrition, (c) classify the studied pomegranate fruit cultivars based on their potential as source of raw materials in processing and their suitability in nutrition.

Accordingly, the research chapters of this dissertation were structured into:

- Chapter 2: constitutes a review of literature on the quality attributes and functional properties of pomegranate fruit relevant to processing and nutrition.
- Chapter 3: characterizes pomegranate fruit cultivars by examining the whole fruit and arils physico-chemical and textural properties.
- Chapter 4: investigates the processing of pomegranate arils and kernels based on their physical, textural and drying dependent physical and textural properties. This chapter also evaluates the proximate and elemental compositions of pomegranate kernels.

- Chapter 5: focuses on the effects of extraction solvents on the quality attributes, functional properties and stability of pomegranate kernel oil.

2. General discussion

2.1. Quality attributes and functional properties of pomegranate fruit (*Punica granatum* L.) relevant to processing and nutrition – a review (**Chapter 2**)

This section reviewed the literature on pomegranate fruit properties and their potential applications in industrial processing and nutrition. The objective was to compare data on the properties of pomegranate fruit harvested in other parts of the world with those grown in South Africa so as to necessitate scientific efforts in postharvest handling and processing of pomegranate fruit.

As highlighted, there are no big variations in the physical properties of several pomegranate cultivars grown in different parts of the world. Measurement of the lineal dimensions (length and diameter) and aril yield of whole fruit of pomegranate fruits harvested in South Africa were similar to pomegranate fruit grown in other countries. However, bigger fruit weight and volume were reported for fruit cultivars harvested in South Africa, Morocco, Tunisia and Croatia (Zaouuay *et al*., 2012; Martínez *et al*., 2012; Fawole & Opara, 2013b; Radunić *et al*., 2015; Hmid *et al*., 2016). Based on this, bigger sizes of aperture and shape of equipment, as well as spacing of slicing discs would be needed for processing pomegranate fruit derived from South Africa, Morocco, Tunisia and Croatia.

In terms of colour, the peel and arils of fruit cultivars of Oman and Israel origin were lighter in comparison to South African pomegranate fruit peel and arils. However, peel and aril redness was higher in South African pomegranate fruit (Al-Said *et al*., 2009; Shwartz *et al*., 2009; Fawole & Opara, 2013b). Since fruit colour is an important sensory attribute, from marketing viewpoint, it would be logical to assume that South African pomegranates would be more appealing to consumers. Among the textural properties, aril and kernel hardness and toughness of pomegranate fruit harvested in South Africa were higher than those of Omani pomegranate (Al-Said *et al*., 2009; Fawole & Opara, 2013b). Again, this information is useful for pomegranate cultivar selection and therefore, influences the marketability of pomegranate fruit cultivars.

Overall, the physical properties of pomegranate fruit are important engineering parameters that may guide processors in designing equipment for harvesting, handling, transporting and processing the whole fruit into other derived products (Stroshine, 1998; Athmaselvi *et al*., 2014). Information on the textural properties of pomegranate fruit may also be relevant in understanding fruit responses to compression, puncture and cutting (Rao & Steffe, 1992). Also, this knowledge could be used to optimize processes and tools for extracting the edible part of pomegranate fruit (Singh & Reddy, 2006; Ekrami-Rad *et al*., 2011). Without the knowledge of the physical and textural properties, processing pomegranate fruit may result in inefficient application and fruit quality losses (Stroshine, 1998; Sirisomboon *et al*., 2007; Athmaselvi *et al*., 2014). In addition, the sensory and chemical characteristics of pomegranate fruit is important in selecting fruit cultivars desirable for end-users.

2.2. Physico-chemical and textural properties relevant to processing of pomegranate fruit and arils (**Chapter 3**)

The growing commercial value of pomegranate in association with the advancement of modern technological expertise for postharvest handling, processing, preservation and distribution of the fruit needs an in-depth knowledge of the fruit physico-chemical and textural properties (Mohsenin, 1970). Unfortunately, lack of such knowledge relevant to processing has plagued the South African pomegranate industry with a high incidence of postharvest losses (Fawole & Opara, 2013a). The aim of this chapter was to categorize three commercial South African pomegranate fruit cultivars (‘Wonderful’, ‘Acco’ and ‘Herskovitz’) by investigating their physico-chemical and textural properties with relevance to processing and nutrition.

The measured colour attributes showed significant ($p < 0.05$) variations in fruit peel, aril and juice colour of the investigated cultivars. The fruit peel of ‘Wonderful’ and ‘Acco’ were characterized as light red and dark red, respectively. However, there were no clear distinctions in aril redness among the cultivars. Whilst juice redness was greater in ‘Wonderful’, no significant difference between ‘Acco’ and ‘Herskovitz’ was observed. The redness of pomegranate is a desirable quality attribute for processors and consumers and as an implication, the peel colour of cv. Acco fruit could be more desirable or appealing.

Furthermore, ‘Wonderful’, ‘Acco’ and ‘Herskovitz’ had 61.62%, 59.66% and 56.98% aril portion, respectively. The edible part (arils) of pomegranate fruit is used extensively in food and beverage industries. In contrast to aril yield, pomegranate juice varied between 67.75 to 74.05 (mL per 100 g arils), with Herskovitz and Acco cultivars having the lowest and the highest amount of juice, respectively. High juice yield is desirable for processors, nutritionists and consumers. Also, the total soluble solids (TSS) of pomegranate juice ranged between 13.48 to 15.93 (°Brix), with the highest and the lowest content in ‘Wonderful’ and ‘Herskovitz’, respectively. Titratable acidity (citric acid) however, was highest (1.32%) in ‘Herskovitz’ and lowest in ‘Acco’ (0.41%). The acidity level of juice determines consumer perceptions of sourness and sweetness (Holland *et al*., 2009). Based on the TSS:TA ratio, the investigated cultivars may be classified as sour ('Wonderful' and 'Herskovitz') and sour-sweet ('Acco') (Martínez *et al*., 2006; Tehranifar *et al*., 2010; Hasnaoui *et al*., 2011).

Whole fruit volume varied significantly among the cultivars with 'Acco' and 'Wonderful' having the biggest and the smallest volume, respectively. Based on the fruit volume, the efficiency of heat and mass transfer in cooling and drying of pomegranate fruit would be in the order 'Wonderful' > 'Herskovitz' > 'Acco' (Oyelade *et al*., 2005; Jahromi *et al*., 2008). Fruit weight, density and size and shape (lineal dimensions and derivatives) were similar among the cultivars. This would enable easy postharvest handling and processing of the three fruit cultivars (Stroshine, 1998; Sirisomboon *et al*., 2007; Athmaselvi *et al*., 2014). However, cv. Wonderful had distinct textural properties. For instance, compressibility, cutting strength and puncture resistance characterised 'Wonderful' fruit as the hardest fruit. On the contrary, 'Acco' fruit was softer than 'Herskovitz' fruit. As an implication, 'Wonderful' fruit would have the advantage of withstanding rough handling. However, the fruit would require higher energy during processing.

A further study on the fruit arils also showed unique qualities for each examined cultivar. The weight and volume of fresh arils were in order of 'Wonderful' > 'Acco' > 'Herskovitz'. However, there were no significant differences in the size (length and diameter) of fresh arils of 'Wonderful' and 'Acco'. Drying of fresh arils resulted in a significant reduction in their weight, size and shape (lineal dimensions and derivatives). This data may be valuable in the design of processing and packaging tools of pomegranate arils (Mohsenin, 1970). Compressibility forces of 35.59 – 40.74 N ruptured pomegranate fresh arils in this study. 'Acco' fresh arils were the softest pomegranate arils while those of 'Wonderful' and 'Herskovitz' required higher compressibility forces. Drying however, increased the textural characteristics of the arils. Knowledge on the textural properties of dried pomegranate arils would be of great interest to processors focusing on shelf stable dried pomegranate aril products.

2.3. Physico-textural and nutritional properties of pomegranate kernel and aril as affected by drying (**Chapter 4**)

This section focusses on potential value-addition to the studied fruit cultivars by investigating the proximate and elemental compositions of the kernels. In addition, the physico-textural, as well as drying dependent physico-textural properties of both pomegranate arils and kernels extracted from the three South African cultivars ('Wonderful', 'Acco' and 'Herskovitz') were studied. The knowledge from this study could inform on the suitability of the cultivars as a source of raw material in nutrition.

The unique physical and textural properties of pomegranate kernels imply the suitability of the investigated cultivars for processing into value-added products. Among the cultivars, both fresh and dried kernels of cv. Acco were the smallest in lineal dimensions and volume. Similar to the arils, drying reduced the physical properties of the kernels. Kernel index, which serve as a relevant attribute for any prospective selection of pomegranate fruit for processing (Martínez *et al.*, 2006), increased two folds after drying. As a result, the kernel weight, size and shape were significantly reduced after drying. Textural profiling characterised fresh kernels of Acco cultivar as the hardest fresh kernel. However, its hardness, toughness and bioyield decreased after drying and this may be explained by its high oil yield and low fibre and carbohydrate contents. The opposite was observed for kernels of 'Wonderful' and 'Herskovitz' as their textural properties were enhanced after drying. Kernel hardness influences prospect of consumer preference since it is an important sensory attribute for fresh pomegranate fruit intended for consumption (Al-Said *et al.*, 2009; Hasnaoui *et al.*, 2011; Szychowski *et al.*, 2015). The study of the physical and textural properties of fresh and dried pomegranate kernels would inform the development of efficient commercial scale processing device or instrument.

Furthermore, knowledge of drying kinetics and drying dependent properties of pomegranate arils and kernels remain critical in the food industry. Drying kinetics indicated that 5 h and 13 h would be enough to sufficiently dry pomegranate kernels and arils, respectively. The drying dependent characteristics of pomegranate arils showed no significant differences in the aril physical properties beyond the drying period however, the textural properties of both dried arils and kernels changed significantly with prolonged drying. Hardness, toughness, bioyield and elastic modulus were predominantly lower for 'Acco' whereas these were considerably higher for 'Wonderful' and 'Herskovitz'. Again, the lower textural properties of arils and kernels of 'Acco' may be attributed to its high oil content and low carbohydrate and dietary fibre content. This knowledge is relevant in the optimization of drying conditions and equipment with necessary mechanical power to process pomegranate kernels (for oil extraction) and arils (as in the case of dried shelf-stable aril).

The evaluation of the nutritional and mineral composition of pomegranate kernels is essential for its value-addition to the food industry. Overall, 'Acco' was the best source of kernel moisture, ash, proteins, fat, total energy and dietary minerals. 'Wonderful' and 'Herskovitz' however, were richer in kernel carbohydrates and dietary fibre contents, respectively. The high levels of kernel oil (17.95 – 27.39%), dietary fibre (31.05 – 36.48%) and energy (1414.68 – 1655.60 kJ/100 g) of the investigated cultivars showed that pomegranate kernels are a rich source of edible and bioactive oil and could be an important source of daily dietary fibre and energy. Furthermore, regardless of the cultivar, the proximate composition of the kernels suggests that they could be exploited for multiple applications in food, cosmeceutical and nutraceutical industries. In addition, the study revealed that mineral elements in pomegranate kernel were abundant in the order Nitrogen > Potassium > Phosphorus > Magnesium > Calcium > Sodium > Iron > Zinc > Copper > Manganese > Boron. The amounts of minerals in the investigated pomegranate kernels are within the recommended daily allowance proposed by the European Union and United States of America (Velíšek, 2014). This further suggests that pomegranate kernels, regardless of cultivar, could contribute substantially in boosting the daily mineral requirements in nutrition hence the need to explore their utilisation in food systems.

2.4. Quality indices, bioactive content, fatty acid composition and stability of pomegranate kernel oil (**Chapter 5**)

The effects of ultrasonic-assisted extraction solvents (*n*-hexane, petroleum ether and acetone) of varying polarity on quality attributes and functional properties of pomegranate kernel oil (PKO) extracted from Wonderful, Acco and Herskovitz fruit cultivars harvested in South Africa are discussed in this section. In addition, the investigation was extended in order to inform processors and nutritionists about the stability of PKO kept under different storage temperatures for 30 days.

Yield of PKO ranged between 16.59 – 27.39% and was in order of ‘Acco’ > ‘Herskovitz’ > ‘Wonderful’, regardless of extraction solvent. As an implication, PKO yield was cultivar dependent and cv. Acco could be considered most desirable for commercial exploration of PKO. The extraction solvent influenced the colour attributes of PKO. Regardless of cultivar, PKO extracted with *n*-hexane and petroleum ether appeared more yellow than PKO extracted with acetone. A similar trend was also observed in the oil colour saturation (C^*) and lightness (L^*). The refractive index (RI) of PKO showed no significant differences among the cultivars and extraction solvents. RI is distinctive of a medium’s density and viscosity and therefore, may imply that all extraction solvents used extracted PKO of similar densities and viscosities.

Total phenolic content (TPC) (0.43 – 8.58 mg GAE/g) of PKO was in the order acetone > *n*-hexane > petroleum ether. The differences in polarity of the extraction solvents could account for the varying phenolic concentrations. Nonetheless, among the cultivar, the order was ‘Acco’ > ‘Herskovitz’ > ‘Wonderful’. This means both extraction solvent and cultivar influenced the abundance of TPC in PKO. The total carotenoid content (TCC) of PKO varied between 0.10 – 0.30 g β-carotene/kg. These high levels are relevant to the functional and nutraceutical properties of PKO (Biehler *et al*., 2010;

Amorim-Carrilho *et al*., 2014; Saini *et al*., 2015). Furthermore, a high DPPH scavenging activity (89.50 – 91.60%) of PKO was observed to be in order of 'Herskovitz' > 'Wonderful' > 'Acco'. This scavenging power of PKO could be attributed to the phenolic and carotenoid compositions of PKO (Yu *et al*., 2005; Aydeniz *et al*., 2014; Saini *et al*., 2015; Yan *et al*., 2016). These findings highlight PKO as a bioactive functional oil, which would be desirable in cosmeceutical and food industries.

A further investigation of the fatty acid compositions of PKO showed no qualitative differences among the cultivars. Overall, the summations of saturated and unsaturated fatty acids were 5.98 – 7.49% and 77.72 – 84.77%, respectively. The amount of punicic acid ranged between 59.90 – 69.85% and was dependent on extraction solvent (petroleum ether > *n*-hexane > acetone). In addition, the use of acetone extracted the highest concentrations of α- and γ-linolenic acids and tocol. Moreover, among the cultivars, tocol was in the order 'Herskovitz' > 'Acco' > 'Wonderful'. The abundance of fatty acids, triterpene, tocol and phytosterol in PKO demonstrate the bioactivity and functional capacity of PKO that could be useful in formulation or fortification of products in cosmeceutical and nutraceutical industries. Assessment of the index of atherogenicity and thrombogenicity also showed that the oil presents no risk of developing cardiovascular diseases hence safe for consumption (Ulbritch & Southgate, 1991; Garaffo *et al*., 2011).

When stored at 25°C (shelf) and 60°C (oven) for 30 days, there were no significant changes in RI of PKO. However, CD, CT and *p*-AV of PKO increased with prolonged storage, regardless of cultivar and extraction solvent. These were indications of oxidation products in the oil. As expected, PKO stored at 60°C underwent an accelerated oxidation making heat a primary factor in enhancing rancidity and developments of undesirable odours in PKO (Poiana, 2012). Nonetheless, there were no significant differences in TCC of PKO kept under the two different storage temperatures. Among the fatty acids, punicic and α- and γ-linolenic acids varied considerably for 60°C stored PKO. The levels of punicic acid decreased with a simultaneous increment in α- and γ-linolenic acids. This may be due to isomerization of the atoms in the molecular structure of these three fatty acids. Nonetheless, these changes were not profound in PKO stored at 25°C. The decrease and increase in punicic and α- and γ-linolenic acids, respectively, may suggest a possible impairment in the functional properties of PKO stored at 60°C. During processing of PKO, it would therefore be important to minimise heat in other to preserve the bioactive and functional properties of the oil. Furthermore, regardless of the storage temperature, the levels of tocol and phytosterol significantly decreased in all investigated PKO. On the contrary, index of atherogenicity (0.04 – 0.05) and thrombogenicity (0.02 – 0.04) of the stored PKO remained low, suggesting no risk of causing immunological and cardiovascular diseases (Ulbritch & Southgate, 1991; Garaffo *et al*., 2011). Interestingly, DPPH scavenging activity of the investigated PKO increased with prolonged storage.

3. General conclusions

In conclusion, the research findings in this thesis provide detailed information on the quality attributes and functional properties of pomegranate fruit and co-products with direct application to processing and nutrition. This thesis presents a pilot study aimed at generating knowledge that will inform pomegranate fruit processors, nutritionists and consumers from value-addition viewpoint, through the utilization of the waste (kernels and oil constituent) generated after juicing the arils. This will also help pomegranate industry to reduce fruit wastage, improve food security and provide marketing access and economic advantage to farmers, processors and nutritionists. Furthermore, this study presents scientific background at which pomegranate cultivars could influence the ease of processing and their suitability as sources of raw materials for health-promoting compounds in nutraceutical industries.

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APPENDIX: CHAPTER 3

Table 1: Pearson correlation coefficient matrix of properties of whole fruit, aril and juice of Wonderful, Acco and Herskovitz pomegranate cultivars

Parameter	Correlation coefficient
WF Weight *vs* CWF Elastic modulus	-0.999
WF Length *vs* Peel Moisture content	0.998
Edible Weight	0.999
WF Diameter *vs* Peel Thickness	0.999
FA *h*°	-0.997
TCD (Peel & PJ)	0.998
WF Shape index *vs* WF Aspect ratio	-1.000
WF Sphericity	-1.000
WF Aspect ratio *vs* WF Sphericity	1.000
FA *h*°	-0.998
WF Geometric mean diameter *vs* WF Surface area	0.999
PJ pH	-0.999
WF Sphericity *vs* FA *h*°	-0.998
WF Surface area *vs* WF Volume of oblate spheroid	0.999
CWF Toughness	0.999
WF Puncture energy	-0.999
WF Volume of oblate spheroid *vs* CWF Toughness	1.000
WF Puncture energy	-1.000
PJ *a**	-0.999
PJ *C**	-0.998
WF Volume *vs* CWF Firmness	-1.000
FA Firmness	-1.000
WF *h*°	-1.000
FA *a**	-0.997
WF Density *vs* XWF Cutting force	1.000
Peel Thickness *vs* TCD (Peel & FA)	0.998
TCD (Peel & PJ)	1.000
Peel Moisture content *vs* Edible weight	1.000
Non-edible weight *vs* %Edible	-1.000
Non-edible**:**Edible	1.000
FA Weight/fruit	-0.998
PJ Total soluble solids	-1.000
Non-edible**:**Edible *vs* %Non-edible	0.998
%Edible	-0.998
FA Weight *vs* FA Length	0.997
PJ *L**	-0.999

Table 1 (continues)

Table 1: Pearson correlation coefficient matrix of properties of whole fruit, aril and juice of Wonderful, Acco and Herskovitz pomegranate cultivars

Parameter	Correlation coefficient
FA Weight/fruit *vs* Non-edible:Edible	-0.999
FA Volume *vs* PJ Total soluble solids	0.999
%Edible	0.999
FA Density *vs* FA Water activity	-1.000
FA *h*°	-1.000
FA Length *vs* FA Geometric mean diameter	0.998
FA Surface area	0.998
FA Volume of oblate spheroid	0.998
FA Diameter *vs* FA Geometric mean diameter	1.000
FA Surface area	1.000
FA Volume of oblate spheroid	1.000
PJ BrimA	0.999
FA Shape index *vs* FA Aspect ratio	-0.998
FA Sphericity	-0.999
PJ Absorbance	-1.000
FA Aspect ratio *vs* FA Sphericity	1.000
FA Elastic modulus	0.997
PJ Absorbance	0.999
FA Geometric mean diameter *vs* FA Surface area	1.000
FA Volume of oblate spheroid	1.000
PJ BrimA	0.998
FA Sphericity *vs* PJ Absorbance	1.000
FA Surface area *vs* FA Volume of oblate spheroid	1.000
PJ BrimA	0.998
FA Volume of oblate spheroid *vs* PJ BrimA	0.998
FA Water activity *vs* PJ *h*°	1.000
DA Weight/fruit *vs* DA Shape index	-0.999
DA Weight *vs* DA Density	-0.997
DA Diameter	0.998
DA Geometric mean diameter	0.998
DA Surface area	0.998
DA Volume of oblate spheroid	0.998
DA Density *vs* DA Geometric mean diameter	-1.000
DA Surface area	-1.000
DA Volume of oblate spheroid	-1.000

Table 1 (continues)

Table 1: Pearson correlation coefficient matrix of properties of whole fruit, aril and juice of Wonderful, Acco and Herskovitz pomegranate cultivars

Parameter	Correlation coefficient
DA Aspect ratio *vs* DA Sphericity	0.999
DA Geometric mean diameter *vs* DA Surface area	1.000
DA Volume of oblate spheroid	1.000
DA Surface area *vs* DA Volume of oblate spheroid	1.000
CWF Bioyield *vs* XWF Firmness	1.000
XWF Toughness	0.997
FA Toughness	0.998
WF *a**	-0.999
WF *C**	-1.000
FA *a**	0.999
FA *C**	1.000
CWF Firmness *vs* FA Firmness	1.000
WF *h*°	0.999
CWF Toughness *vs* WF Puncture energy	-1.000
FA *b**	-1.000
PJ *a**	-0.999
PJ *C**	-0.998
XWF Elastic modulus *vs* WF *L**	-1.000
PJ Yield	1.000
PJ Titratable acidity	-0.999
XWF Firmness *vs* TCD (FA & PJ)	-0.997
XWF Toughness	0.998
FA Toughness	0.999
WF *a**	-0.999
WF *C**	-1.000
FA *a**	0.998
FA *C**	1.000
XWF Toughness *vs* WF Puncture resistance	0.999
FA Toughness	1.000
WF *C**	-0.998
FA *C**	0.999
TCD (FA & PJ)	-1.000
WF Puncture resistance *vs* FA Toughness	0.999
TCD (FA & PJ)	-1.000

Table 1 (continues)

Table 1: Pearson correlation coefficient matrix of properties of whole fruit, aril and juice of Wonderful, Acco and Herskovitz pomegranate cultivars

Parameter	Correlation coefficient
WF Puncture energy *vs* FA b*	1.000
PJ a*	0.998
PJ C*	0.998
FA Bioyield *vs* FA Rupture force	-0.999
PJ TSS:TA	0.998
FA Elastic modulus *vs* DA Hardness	0.999
PJ BrimA	0.997
FA Rupture force *vs* PJ TSS:TA	-1.000
FA Firmness *vs* WF h°	0.999
FA Toughness *vs* WF C*	-0.998
FA C*	0.999
TCD (FA & PJ)	-1.000
DA Elastic modulus *vs* WF L*	1.000
PJ Yield	-1.000
DA Hardness *vs* PJ Absorbance	0.997
DA Toughness *vs* PJ L*	-0.998
PJ b*	0.998
WF L* *vs* PJ Yield	-1.000
PJ Titratable acidity	0.997
WF a* *vs* WF C*	0.999
WF h°	-0.997
FA a*	-1.000
FA C*	-0.998
WF b* *vs* FA L*	1.000
WF C* *vs* FA a*	-0.998
FA C*	-1.000
WF h° *vs* FA a*	0.999
FA a* *vs* FA C*	0.997
FA b* *vs* PJ a*	0.999
PJ C*	0.998
FA C* *vs* TCD (FA & PJ)	-0.998
PJ L* *vs* PJ b*	-1.000
PJ a* *vs* PJ C*	1.000
TCD (Peel & FA)	-0.999

Table 1 (continues)

Table 1: Pearson correlation coefficient matrix of properties of whole fruit, aril and juice of Wonderful, Acco and Herskovitz pomegranate cultivars

Parameter	Correlation coefficient
PJ *C** *vs* TCD (Peel & FA)	-0.999
TCD (Peel & FA) *vs* TCD (Peel & PJ)	0.999
PJ Yield *vs* PJ Titratable acidity	-0.997
PJ Total soluble solids *vs* %Non-edible	-1.000
%Edible	1.000
Non-edible:Edible	-0.999

Whole fruit (WF), Compressibility of whole fruit (CWF), Cutting strength of whole fruit (XWF), Fresh aril (FA), Dried aril (DA), Pomegranate juice (PJ), Lightness (*L**), Redness (*a**), Yellowness (*b**), Chroma (*C**), Hue angle (*h*°), Total colour difference (TCD), Versus (*vs*).

Table 2: Factor scores, factor loadings, Eigen values, variance (%) and cumulative variance (%) for F1 and F2 factors based on measured properties of whole fruit, aril and juice of Wonderful, Acco and Herskovitz pomegranate cultivars

Factor scores		
Observation	F1	F2
Wonderful	-10.492	0.501
Acco	4.699	-7.458
Herskovitz	5.793	6.957
Factor loadings		
WF Weight	0.296	-0.955
WF Length	-0.912	-0.411
WF Diameter	0.993	0.119
WF Shape index	-0.960	-0.278
WF Aspect ratio	0.968	0.249
WF Dg	0.983	-0.183
WF Sphericity index	0.967	0.255
WF Surface area	0.991	-0.131
WF VSP	0.996	-0.084
WF Volume	0.847	-0.532
WF Density	-0.659	0.752
Peel Thickness	0.998	0.070
Peel Moisture content	-0.933	-0.359
Non-edible Weight	0.834	0.552
Edible Weight	-0.928	-0.373
Non-edible (%)	0.851	0.525
Edible (%)	-0.851	-0.525
Non-edible**:**Edible	0.821	0.572
Number of arils/fruit	0.731	0.682
FA Weight/fruit	-0.796	-0.606
FA Weight	-0.662	-0.749
FA Volume	-0.874	-0.486
FA Density	0.232	0.973
FA Length	-0.602	-0.798
FA Diameter	-0.536	-0.844
FA Shape index	0.313	0.950
FA Aspect ratio	-0.370	-0.929
FA Dg	-0.553	-0.833
FA Sphericity index	-0.348	-0.937
FA Surface area	-0.555	-0.832
FA VSP	-0.557	-0.830
FA Moisture content	0.575	-0.818
FA water activity	-0.248	-0.969
DA Weight/fruit	-0.745	0.667
DA Weight	-0.991	0.132
DA Volume	-0.999	-0.048
DA Density	0.998	-0.059
DA Length	-0.822	-0.570
DA Diameter	-0.980	0.200
DA Shape index	0.723	-0.691
DA Aspect ratio	-0.850	0.527
DA Dg	-0.997	0.077
DA Sphericity index	-0.824	0.566
DA Surface area	-0.997	0.076
DA VSP	-0.997	0.076
DA water activity	-0.999	-0.052
CWF Bioyield	-0.906	0.422
CWF Elastic modulus	-0.257	0.967
CWF Firmness	-0.835	0.550
CWF Toughness	0.996	-0.090
XWF Cutting force	-0.644	0.765
XWF Elastic modulus	0.091	-0.996
XWF Firmness	-0.911	0.413
XWF Toughness	-0.935	0.355
WF Puncture resistance	-0.948	0.320
WF Puncture energy	-0.996	0.092
FA Bioyield	0.472	-0.881
FA Elastic modulus	-0.436	-0.900
FA Rupture force	-0.428	0.904
FA Firmness	-0.833	0.553
FA Toughness	-0.930	0.367
DA Bioyield	0.611	-0.792
DA Elastic modulus	-0.044	0.999
DA Hardness	-0.390	-0.921
DA Toughness	-0.747	-0.665

Table 2 (continues)

Table 2: Factor scores, factor loadings, Eigen values, variance (%) and cumulative variance (%) for F1 and F2 factors based on measured properties of whole fruit, aril and juice of Wonderful, Acco and Herskovitz pomegranate cultivars

Factor loadings		
Observation	F1	F2
WF Lightness, *L**	-0.065	0.998
WF Redness, *a**	0.892	-0.452
WF Yellowness, *b**	-0.779	0.627
WF Chroma, *C**	0.908	-0.419
WF Hue, h^0	-0.857	0.515
FA Lightness, *L**	-0.766	0.643
FA Redness, *a**	-0.883	0.469
FA Yellowness, *b**	-0.996	0.089
FA Chroma, *C**	-0.917	0.399
FA Hue, h^0	-0.982	-0.191
PJ Lightness, *L**	0.700	0.714
PJ Redness, *a**	-0.999	0.036
PJ Yellowness, *b**	-0.700	-0.715
PJ Chroma, *C**	-1.000	0.025
PJ Hue, h^0	-0.221	-0.975
PJ Absorbance	-0.323	-0.946
TCD (Peel & Aril)	1.000	0.008
TCD (Aril & PJ)	0.939	-0.343
TCD (Peel & PJ)	0.999	0.054
PJ Yield	0.067	-0.998
PJ pH	-0.974	0.228
PJ Total soluble solids	-0.849	-0.529
PJ Titratable acidity	-0.142	0.990
PJ TSS:TA	0.411	-0.912
PJ BrimA	-0.503	-0.864
Eigenvalue	55.245	34.755
Variability (%)	61.383	38.617
Cumulative %	61.383	100.000

Whole fruit (WF), Compressibility of whole fruit (CWF), Cutting strength of whole fruit (XWF), Fresh aril (FA), Dried aril (DA), Pomegranate juice (PJ), Aspect ratio (A_R), Geometric mean diameter (Dg), Sphericity index (φ), Surface area (S_F), Volume of oblate spheroid (VSP), Number of arils per fruit (No_Arils/fruit), Water activity (a_w), Titratable acidity (TA), Total soluble solids (TSS), Total colour difference (TCD).

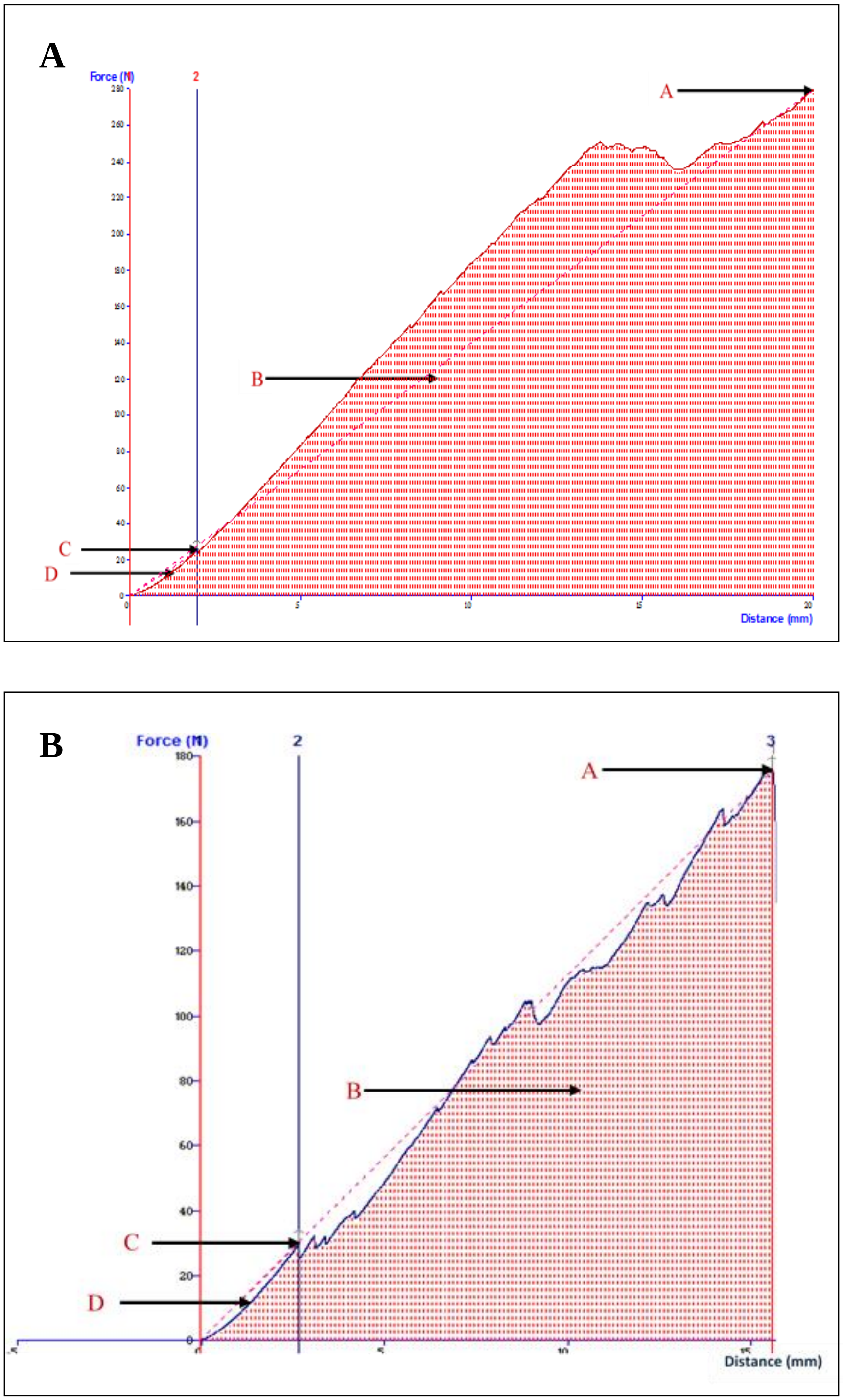

Fig. 1: A typical force-deformation curve showing (**A**) a compressibility profile for a pomegranate fruit under compression and (**B**) a cutting strength profile for a pomegranate fruit under cutting with labels;

A – Firmness (N)
B – Toughness (N mm) (area under curve)
C – Bioyield force (N) (**A**)/Cutting Force (N) (**B**)
D – Young's or elastic modulus (N/mm) (gradient)

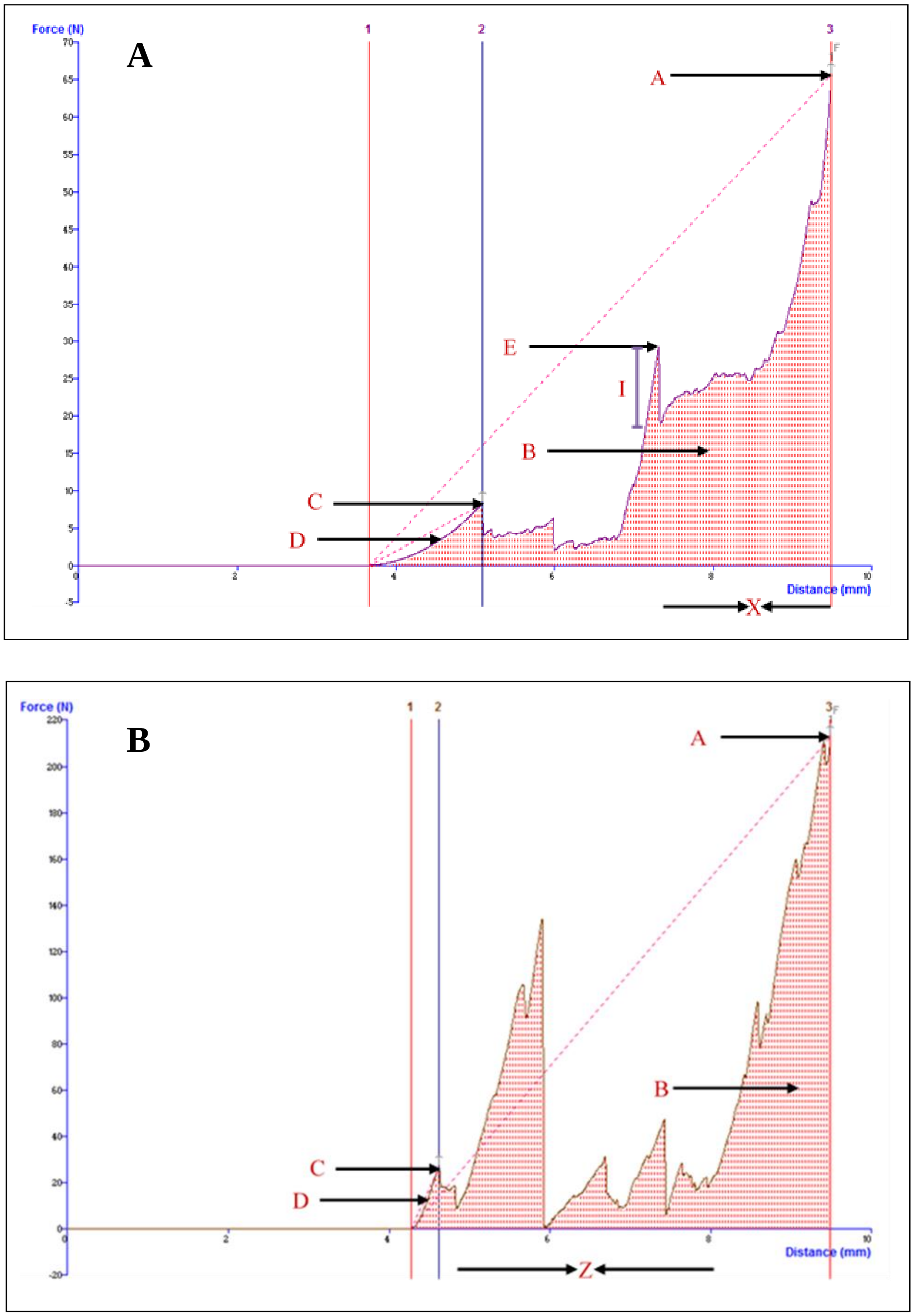

Fig. 2. A typical force-deformation curve showing a compressibility profile for (**A**) a fresh aril and (**B**) a dried aril with labels;

A – Firmness (N) (**A**)/Hardness (N) (**B**)
B – Toughness (N mm) (area under compression curve)
C – Bioyield (N)
D – Young's or elastic modulus (N/mm) (gradient)
E – Rupture force (N)
I – Distance between aril membrane and kernel testa
X – Influences of kernel in aril
Z – Characteristics of a dry aril's stickiness

APPENDIX: CHAPTER 4

Table 1: *P*-values for drying dependent water activity and textural properties of arils and conditioned kernels of Wonderful, Acco and Herskovitz pomegranate cultivars

Property	Cultivar **(A)**	Drying time **(B)**	Cultivar × Drying time **(A × B)**
Arils			
Water activity	<0.0001	<0.0001	<0.0001
Hardness (N)	<0.0001	<0.0001	<0.0001
Toughness (N mm)	<0.0001	<0.0001	<0.0001
Bioyield (N)	<0.0001	<0.0001	<0.0001
Elastic modulus (N/mm)	<0.0001	<0.0001	<0.0001
Conditioned kernels			
Water activity	<0.0001	<0.0001	<0.0001
Hardness (N)	<0.0001	<0.0001	0.3908
Toughness (N mm)	<0.0001	0.2426	0.6237
Bioyield (N)	<0.0001	0.0560	0.5618
Elastic modulus (N/mm)	<0.0001	<0.0001	0.7410

Red ink designates a significant level and hence a determining factor.

Table 2: Factor scores, factor loadings, Eigen values, variance (%) and cumulative variance (%) for F1 and F2 factors based on kernel properties of Wonderful, Acco and Herskovitz pomegranate cultivars

Factor scores		
Observation	F1	F2
Wonderful	-5.534	4.978
Acco	9.012	0.820
Herskovitz	-3.477	-5.798

Factor loadings		
Number of kernels/fruit	-0.156	-0.988
FK Weight/fruit	-0.624	-0.782
FK Weight	-0.601	0.799
FK Kernel index	-0.469	-0.883
FK Volume	-0.484	0.875
FK Density	0.665	-0.747
FK Length	-0.957	-0.292
FK Diameter	-0.969	0.247
FK Shape index	0.965	-0.263
FK Aspect ratio	-0.922	0.388
FK Dg	-0.983	0.182
FK Sphericity	-0.928	0.373
FK Surface area	-0.979	0.202
FK VSP	-0.974	0.225
FK Water activity	0.087	-0.996
DK Weight/fruit	-0.934	-0.357
DK Weight	-0.937	0.350
DK Kernel index	-0.316	-0.949
DK Volume	-0.356	0.934
DK Density	-0.189	-0.982
DK Length	-0.897	-0.443
DK Diameter	-0.936	0.352
DK Shape index	0.740	-0.672
DK Aspect ratio	-0.753	0.658
DK Dg	-0.977	0.214
DK Sphericity	-0.744	0.669
DK Surface area	-0.974	0.226
DK VSP	-0.971	0.239
DK Water activity	0.659	0.752
FK Bioyield	-0.991	-0.134
FK Elastic modulus	-0.944	-0.330
FK Hardness	0.817	0.576
FK Toughness	-0.054	0.999
DK Bioyield	-0.998	0.058
DK Elastic modulus	-0.746	0.666
DK Hardness	-0.978	-0.207
DK Toughness	-0.992	-0.125
Moisture	0.989	0.147
KP Water activity	-0.470	-0.883
Ash	0.907	-0.422
Fat	1.000	-0.001
Fat energy	1.000	-0.001
Dietary fibre	-0.593	-0.805
Protein	0.805	0.593
Protein energy	0.805	0.593
Carbohydrate	-0.892	0.452
Carbohydrate energy	-0.892	0.452
Total energy	0.918	0.397
Nitrogen, N	0.996	0.088
Phosphorus, P	0.999	-0.044
Potassium, K	0.993	-0.119
Calcium, Ca	0.192	0.981
Magnesium, Mg	0.999	-0.047
Sodium, Na	0.969	-0.247
Manganese, Mn	0.859	0.513
Iron, Fe	0.977	0.212
Copper, Cu	0.993	-0.119
Zinc, Zn	1.000	-0.014
Boron, B	0.718	0.696
Eigen value	41.309	19.691
Variance (%)	67.720	32.280
Cum. variance (%)	67.720	100.00

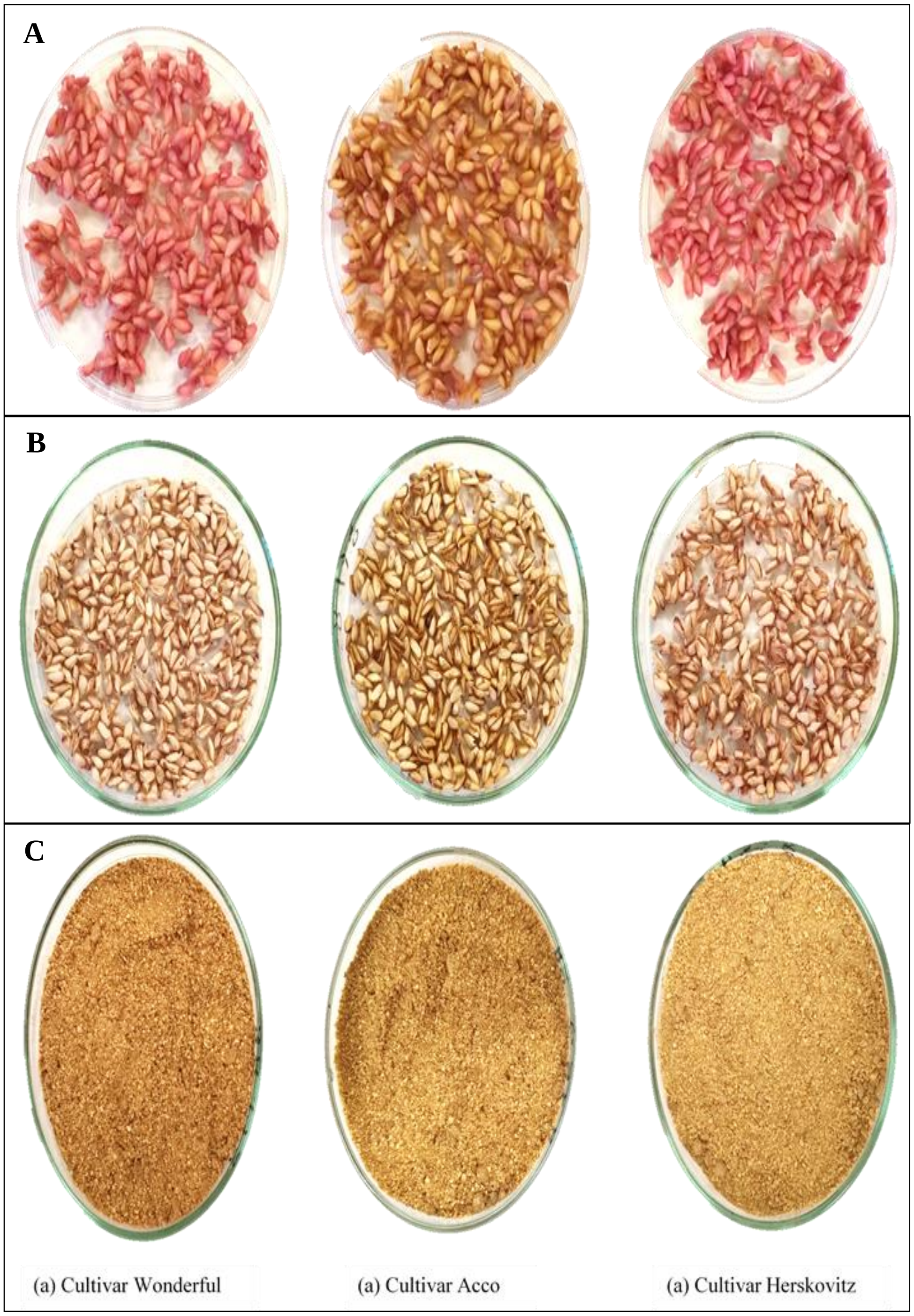

Fig. 1. Fresh kernels (A); Oven dried kernels (B); and Kernel powder (C) of Wonderful, Acco and Herskovitz pomegranate cultivars

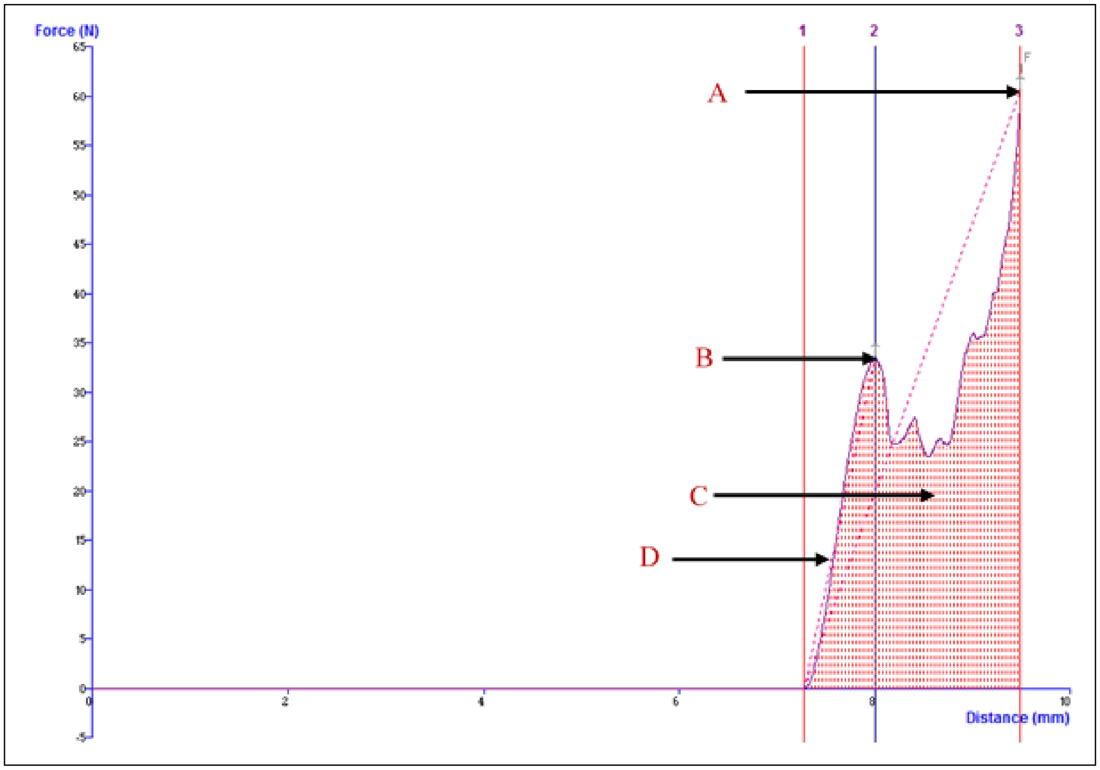

Fig. 2. A typical force-deformation curve showing a compressibility profile for a pomegranate kernel

A – Hardness (N)
B – Bioyield (N)
C – Toughness (N mm) (area under compression curve)
D – Young's or elastic modulus (N/mm) (gradient)

APPENDIX: CHAPTER 5

Table 1: *P*-values for CIE colour attributes of pomegranate kernel oil of 'Wonderful', 'Acco' and 'Herskovitz' extracted with three solvents

Attribute	Cultivar **(A)**	Solvent **(B)**	Cultivar × Solvent **(A × B)**
*L**	0.9776	<0.0001	0.2581
a*	0.2262	0.6364	0.2606
*b**	0.9495	<0.0001	0.1008
*C**	0.8987	<0.0001	0.1093
h°	0.0892	<0.0001	0.0892

Red ink designates a significant level and hence a determining factor.

Lightness (*L**), redness (a*), yellowness (*b**), chroma (*C**), hue angle (*h*°).

Table 2: *P*-values for oil yield, indices and chemical properties of pomegranate kernel oil of 'Wonderful', 'Acco' and 'Herskovitz' extracted with three solvents

Property	Cultivar **(A)**	Solvent **(B)**	Cultivar × Solvent **(A × B)**
Yield (%)	<0.0001	0.5300	0.9852
Index			
CD (unit)	<0.0001	<0.0001	<0.0001
CT (unit)	0.1913	<0.0001	<0.0001
p-AV	<0.0001	<0.0001	0.6400
Chemical			
TPC (mg GAE/g)	<0.0001	<0.0001	0.0574
$TCC_{440\ nm}$ (g β-Carotene/kg)	<0.0001	0.0658	<0.0001
$TCC_{460\ nm}$ (g β-Carotene /kg)	<0.0001	<0.0001	<0.0001
DPPH (% RSA)	<0.0001	0.9926	0.3718

Red ink designates a significant level and hence a determining factor.

Conjugated dienes (CD), Conjugated trienes (CT), *para*-Anisidine value (*p*-AV), Total phenolic content (TPC), Total carotenoid content (TCC), Radical scavenging activity (RSA).

Table 3: *P*-values for fatty acid and derivatives, triterpene, tocol and phytosterol compositions of pomegranate kernel oil of ‘Wonderful’, ‘Acco’ and ‘Herskovitz’ extracted with three solvents

Composition (%)	Cultivar **(A)**	Solvent **(B)**	Cultivar × Solvent **(A × B)**
SFA			
Palmitic (C16:0)	0.4215	0.3277	0.7749
Stearic (C18:0)	<0.0001	0.4544	0.2047
Arachidic (C20:0)	0.2233	0.3894	0.6322
MUFA			
Oleic (C18:1)	<0.0001	0.5102	0.3212
Vaccenic (C18:1)	0.1492	0.4082	0.2332
Goindoic (C20:1)	0.1149	<0.0001	<0.0001
PUFA			
Linoleic (C18:2)	0.1862	0.5724	0.2222
Punicic (C18:3)	0.6163	<0.0001	0.5379
α-Linolenic (C18:3)	0.1753	<0.0001	0.7569
γ-Linolenic (C18:3)	<0.0001	<0.0001	0.1331
Others			
Triterpene (squalene)	0.3283	0.9013	0.4257
Tocol (γ-tocopherol)	<0.0001	0.0815	0.2666
Phytosterol (γ-sitosterol)	0.1200	0.3499	0.1276
Derivative			
∑SFA	0.6827	0.3147	0.3393
∑MUFA	0.1315	0.2779	0.3300
∑PUFA	0.5051	0.1713	0.2737
∑UFA	0.5100	0.2904	0.2988
PUFA/MUFA	0.0804	0.1313	0.2071
SFA/MUFA	0.0583	0.2769	0.3053
SFA/PUFA	0.6006	0.1804	0.2873
SFA/UFA	0.6051	0.1886	0.2940
Index of atherogenicity	0.8222	0.1179	0.3319
Index of thrombogenicity	0.7582	0.1437	0.3137

Red ink designates a significant level and hence a determining factor.

Saturated fatty acid (SFA), Monounsaturated fatty acid (MUFA), Polyunsaturated fatty acid (PUFA), Summation of (∑), Unsaturated fatty acid (UFA).

Table 4: *P*-values for changes in indices and chemical properties of pomegranate kernel oil of 'Wonderful', 'Acco' and 'Herskovitz' subjected to different storage temperatures and duration

Property	Cultivar **(A)**	Solvent **(B)**	Storage **(C)**	Cultivar × Solvent **(A×B)**	Cultivar × Storage **(A×C)**	Solvent × Storage **(B×C)**	Cultivar × Solvent × Storage **(A×B×C)**
Index							
CD (unit)	0.3008	0.3004	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CT (unit)	0.0851	<0.0001	<0.0001	0.7753	0.6794	0.0838	<0.0001
p-AV	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chemical							
$TCC_{440\ nm}$ (g β-Carotene/kg)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
$TCC_{460\ nm}$ (g β-Carotene /kg)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
DPPH (% RSA)	<0.0001	<0.0001	<0.0001	0.3216	<0.0001	0.1640	<0.0001

Red ink designates a significant level and hence a determining factor.

Refractive index (RI), Conjugated dienes (CD), Conjugated trienes (CT), *para*-Anisidine value (*p*-AV), Total carotenoid content (TCC), Radical scavenging activity (RSA).

Table 5: *P*-values for changes in fatty acids and derivatives, triterpene, tocol and phytosterol in pomegranate kernel oil subjected to different storage temperatures and duration

Property	Cultivar **(A)**	Solvent **(B)**	Storage **(C)**	Cultivar × Solvent **(A×B)**	Cultivar × Storage **(A×C)**	Solvent × Storage **(B×C)**	Cultivar × Solvent × Storage **(A×B×C)**
SFA							
Palmitic	0.4209	0.3569	0.2267	0.8296	0.8646	0.2742	0.9872
Stearic	<0.0001	0.1644	<0.0001	0.6920	0.3658	0.7699	0.9705
Arachidic	0.3289	0.6910	<0.0001	0.8624	0.4561	0.2627	0.9977
MUFA							
Oleic	<0.0001	0.3639	<0.0001	<0.0001	<0.0001	0.2984	0.5817
Vaccenic	<0.0001	0.5681	<0.0001	0.2032	<0.0001	0.4749	0.2822
Goindoic	<0.0001	0.0575	<0.0001	<0.0001	0.0577	0.1891	0.5399
PUFA							
Linoleic	<0.0001	0.5594	0.1435	0.3332	0.0650	0.2316	0.5402
Punicic	0.0710	0.1215	<0.0001	0.4676	<0.0001	<0.0001	0.3482
α-Linolenic	0.5000	0.1629	<0.0001	0.3582	0.0560	0.2075	0.2710
γ-Linolenic	<0.0001	0.2700	<0.0001	0.9791	<0.0001	<0.0001	<0.0001
Others							
Triterpene (squalene)	<0.0001	0.2362	<0.0001	0.1576	0.1531	0.6337	<0.0001
Tocol (γ-tocopherol)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0562
Phytosterol (γ-sitosterol)	<0.0001	0.9503	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Red ink designates a significant level and hence a determining factor.

Table 5 (continues)

Table 5: *P*-values for changes in fatty acids and derivatives, triterpene, tocol and phytosterol in pomegranate kernel oil subjected to different storage temperatures and duration

Property	Cultivar **(A)**	Solvent **(B)**	Storage **(C)**	Cultivar × Solvent **(A×B)**	Cultivar × Storage **(A×C)**	Solvent × Storage **(B×C)**	Cultivar × Solvent × Storage **(A×B×C)**
Derivative							
∑SFA	<0.0001	0.2761	0.0516	0.8186	0.6347	0.4401	0.9930
∑MUFA	<0.0001	0.2444	<0.0001	0.0597	<0.0001	0.3328	0.7390
∑PUFA	<0.0001	0.5732	<0.0001	0.3388	0.2387	0.2072	0.8152
∑UFA	<0.0001	0.8533	<0.0001	0.2415	0.1063	0.1657	0.3675
PUFA/MUFA	<0.0001	0.4494	<0.0001	0.0835	0.0543	0.2075	0.6461
SFA/MUFA	<0.0001	0.5068	<0.0001	0.0508	<0.0001	0.4684	0.1730
SFA/PUFA	<0.0001	0.3328	0.0967	0.7699	0.5217	0.3672	0.9890
SFA/UFA	<0.0001	0.3588	0.0790	0.8113	0.5722	0.3819	0.9880
Index of atherogenicity	0.0569	0.2474	0.1007	0.8073	0.3969	0.2902	0.9878
Index of thrombogenicity	<0.0001	0.2713	0.1912	0.7775	0.4679	0.3416	0.9893

Red ink designates a significant level and hence a determining factor.

Table 6: Changes in fatty acids and triterpene in pomegranate kernel oil subjected to different storage temperatures and duration

		Cultivar								
		Wonderful			Acco			Herskovitz		
Property	Storage (days)	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone
Palmitic (C16:0)	Day 0	4.12±0.52^{bc}	3.49±0.34^{bc}	4.14±0.62^{bc}	3.69±0.12^{bc}	3.68±0.12^{bc}	3.94±0.05^{bc}	3.90±0.24^{bc}	4.08±0.27^{bc}	4.45±0.25^{abc}
	SH 10	3.96±0.09^{bc}	4.60±0.84^{ab}	4.03±0.11^{bc}	4.42±0.14^{abc}	3.99±0.07^{bc}	4.17±0.06^{bc}	4.18±0.05^{bc}	3.94±0.32^{bc}	4.25±0.00^{bc}
	SH 20	3.86±0.17^{bc}	3.97±0.13^{bc}	3.56±0.12^{bc}	3.80±0.09^{bc}	4.18±0.29^{bc}	3.79±0.12^{bc}	3.97±0.31^{bc}	3.83±0.28^{bc}	3.72±0.22^{bc}
	SH 30	4.25±0.16^{bc}	4.25±0.03^{bc}	3.82±0.24^{bc}	4.12±0.30^{bc}	3.99±0.15^{bc}	3.89±0.33^{bc}	4.22±0.10^{bc}	4.17±0.20^{bc}	3.69±0.37^{bc}
	OV 10	5.59±2.33^{a}	3.73±0.13^{bc}	4.33±1.04^{abc}	4.38±0.41^{abc}	3.07±0.01^{c}	3.69±0.20^{bc}	4.14±0.00^{bc}	4.05±0.05^{bc}	3.94±0.08^{bc}
	OV 20	3.71±0.16^{bc}	3.79±0.08^{bc}	3.70±0.13^{bc}	3.88±0.14^{bc}	3.64±0.06^{bc}	3.56±0.31^{bc}	3.55±0.20^{bc}	4.15±0.41^{bc}	3.32±0.07^{bc}
	OV 30	3.96±0.07^{bc}	4.05±0.18^{bc}	4.17±0.06^{bc}	3.99±0.37^{bc}	4.04±0.18^{bc}	3.73±0.06^{bc}	3.83±0.07^{bc}	4.15±0.07^{bc}	4.02±0.33^{bc}
Stearic (C18:0)	Day 0	2.82±0.43^{a-h}	2.03±0.23^{h}	2.12±0.29^{fgh}	2.73±0.24^{b-h}	2.70±0.10^{b-h}	2.84±0.04^{a-h}	2.08±0.14^{gh}	2.20±0.17^{e-h}	2.44±0.03^{d-h}
	SH 10	2.54±0.14^{c-h}	2.95±0.42^{a-h}	2.58±0.12^{c-h}	3.67±0.07^{ab}	3.26±0.00^{a-d}	3.46±0.09^{abc}	2.52±0.03^{c-h}	2.50±0.11^{c-h}	2.50±0.01^{c-h}
	SH 20	2.22±0.06^{e-h}	2.35±0.01^{d-h}	2.19±0.08^{e-h}	2.93±0.02^{a-h}	3.17±0.20^{a-e}	2.93±0.02^{a-h}	2.35±0.02^{d-h}	2.30±0.07^{d-h}	2.32±0.23^{d-h}
	SH 30	2.70±0.12^{b-h}	2.59±0.03^{c-h}	2.32±0.16^{d-h}	2.98±0.16^{a-h}	3.11±0.07^{a-f}	3.13±0.24^{a-e}	2.32±0.00^{d-h}	2.26±0.24^{e-h}	2.25±0.32^{e-h}
	OV 10	3.66±1.64^{ab}	3.17±0.47^{a-e}	2.80±0.67^{a-h}	3.72±0.23^{a}	2.62±0.01^{c-h}	2.92±0.14^{a-h}	2.52±0.00^{c-h}	2.51±0.02^{c-h}	2.36±0.05^{d-h}
	OV 20	2.53±0.11^{c-h}	2.55±0.07^{c-h}	2.37±0.13^{d-h}	3.09±0.17^{a-f}	3.04±0.05^{a-g}	3.01±0.33^{a-h}	2.26±0.02^{e-h}	2.46±0.19^{d-h}	2.06±0.01^{gh}
	OV 30	2.56±0.12^{c-h}	2.52±0.19^{c-h}	2.50±0.05^{c-h}	3.02±0.12^{a-g}	3.15±0.17^{a-e}	2.76±0.02^{a-h}	2.35±0.09^{d-h}	2.36±0.00^{d-h}	2.20±0.20^{e-h}
Arachidic (C20:0)	Day 0	0.52±0.06^{b-f}	0.46±0.05^{b-f}	0.50±0.08^{b-f}	0.50±0.00^{b-f}	0.53±0.06^{b-f}	0.59±0.00^{b-f}	0.51±0.02^{b-f}	0.59±0.00^{b-f}	0.60±0.06^{b-f}
	SH 10	0.53±0.01^{b-f}	0.66±0.10^{a-e}	0.53±0.02^{b-f}	0.72±0.04^{abc}	0.61±0.00^{b-f}	0.66±0.00^{a-e}	0.55±0.01^{b-f}	0.57±0.01^{b-f}	0.59±0.01^{b-f}
	SH 20	0.52±0.02^{b-f}	0.48±0.02^{b-f}	0.49±0.02^{b-f}	0.50±0.03^{b-f}	0.54±0.04^{b-f}	0.48±0.02^{b-f}	0.52±0.04^{b-f}	0.53±0.04^{b-f}	0.50±0.09^{b-f}
	SH 30	0.58±0.05^{b-f}	0.53±0.04^{b-f}	0.47±0.03^{b-f}	0.53±0.08^{b-f}	0.55±0.01^{b-f}	0.49±0.00^{b-f}	0.50±0.02^{b-f}	0.48±0.10^{b-f}	0.44±0.10^{b-f}
	OV 10	0.89±0.43^{a}	0.61±0.06^{b-f}	0.67±0.29^{a-d}	0.73±0.09^{ab}	0.42±0.01^{def}	0.56±0.03^{b-f}	0.64±0.05^{a-f}	0.55±0.01^{b-f}	0.51±0.00^{b-f}
	OV 20	0.36±0.01^{ef}	0.58±0.01^{b-f}	0.45±0.09^{b-f}	0.54±0.05^{b-f}	0.52±0.06^{b-f}	0.55±0.14^{b-f}	0.43±0.09^{c-f}	0.45±0.06^{b-f}	0.41±0.06^{def}
	OV 30	0.35±0.01^{f}	0.46±0.11^{b-f}	0.43±0.08^{c-f}	0.43±0.00^{c-f}	0.44±0.00^{b-f}	0.42±0.02^{def}	0.35±0.00^{f}	0.36±0.01^{f}	0.43±0.07^{c-f}

For each property, values followed by different letters, regardless of the row and column, are significantly different at 5% level by Duncan Multiple Range Test. Storage refers to storage temperature & duration (days), Shelf stored at 25°C (SH), Oven stored at 60°C (OV).

Table 6 (continues)

Table 6: Changes in fatty acids and triterpene in pomegranate kernel oil subjected to different storage temperatures and duration

Property	Storage (days)	Cultivar								
		Wonderful			Acco			Herskovitz		
		Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone
Oleic (C18:1)	Day 0	$5.28\pm0.81^{f-q}$	3.66 ± 0.42^{q}	$4.68\pm0.87^{l-q}$	$5.54\pm0.48^{f-q}$	$5.70\pm0.17^{f-p}$	$5.97\pm0.00^{d-p}$	$4.66\pm0.10^{l-q}$	$4.70\pm0.41^{k-q}$	4.19 ± 0.25^{pq}
	SH 10	$4.84\pm0.22^{i-q}$	$5.80\pm1.80^{d-p}$	$5.04\pm0.42^{h-q}$	8.57 ± 0.03^{a}	$6.83\pm0.01^{a-h}$	$7.74\pm0.14^{a-d}$	$5.76\pm0.21^{e-p}$	$6.00\pm0.55^{d-p}$	$6.44\pm0.07^{b-m}$
	SH 20	$4.49\pm0.13^{m-q}$	$5.31\pm0.37^{f-q}$	4.32 ± 0.14^{opq}	$7.69\pm0.39^{a-e}$	$7.65\pm0.99^{a-e}$	$7.68\pm0.10^{a-e}$	$6.15\pm1.16^{c-p}$	$6.78\pm0.41^{a-j}$	$5.77\pm0.04^{e-p}$
	SH 30	$4.69\pm0.09^{l-q}$	$4.62\pm0.18^{l-q}$	$4.43\pm0.09^{n-q}$	$6.82\pm0.37^{a-i}$	$5.52\pm0.17^{f-l}$	$5.58\pm0.02^{f-q}$	$5.24\pm0.01^{f-q}$	$5.45\pm0.09^{f-q}$	$4.88\pm0.01^{h-q}$
	OV 10	$7.09\pm2.40^{a-g}$	$5.13\pm0.27^{g-q}$	$5.99\pm1.20^{d-p}$	8.10 ± 1.10^{ab}	$5.97\pm0.00^{d-p}$	$6.07\pm0.31^{c-p}$	$5.16\pm0.02^{g-q}$	$5.32\pm0.02^{f-q}$	$5.52\pm0.17^{f-q}$
	OV 20	$4.80\pm0.18^{j-q}$	$4.61\pm0.27^{l-q}$	$5.33\pm0.45^{f-q}$	7.95 ± 0.25^{abc}	$7.14\pm0.30^{a-f}$	$6.55\pm0.64^{b-l}$	$4.63\pm0.17^{l-q}$	$6.85\pm1.04^{a-h}$	$5.07\pm0.29^{h-q}$
	OV 30	$4.46\pm0.09^{m-q}$	$4.64\pm0.05^{l-q}$	$4.88\pm0.33^{h-q}$	$6.19\pm0.06^{b-o}$	$6.31\pm0.04^{b-n}$	$6.67\pm0.03^{a-k}$	$4.98\pm0.05^{h-q}$	$5.17\pm0.02^{g-q}$	$5.41\pm0.06^{f-q}$
Vaccenic (C18:1)	Day 0	$0.86\pm0.29^{a-e}$	0.46 ± 0.04^{f}	0.55 ± 0.08^{def}	0.42 ± 0.03^{f}	0.43 ± 0.02^{f}	0.46 ± 0.00^{f}	0.51 ± 0.02^{def}	0.54 ± 0.00^{def}	$0.59\pm0.05^{c-f}$
	SH 10	0.55 ± 0.01^{def}	$0.70\pm0.20^{b-f}$	$0.57\pm0.04^{c-f}$	0.56 ± 0.00^{def}	0.51 ± 0.00^{def}	$0.80\pm0.24^{a-f}$	$0.60\pm0.02^{c-f}$	$0.59\pm0.04^{c-f}$	$0.62\pm0.02^{b-f}$
	SH 20	0.52 ± 0.01^{def}	$0.58\pm0.03^{c-f}$	0.50 ± 0.01^{def}	0.52 ± 0.03^{def}	0.51 ± 0.04^{def}	$0.76\pm0.25^{a-f}$	$0.65\pm0.13^{b-f}$	1.01 ± 0.27^{ab}	$0.60\pm0.01^{c-f}$
	SH 30	$0.67\pm0.07^{b-f}$	$0.59\pm0.00^{c-f}$	0.55 ± 0.02^{def}	0.50 ± 0.03^{def}	0.47 ± 0.00^{ef}	0.47 ± 0.00^{ef}	0.55 ± 0.00^{def}	$0.58\pm0.00^{c-f}$	0.54 ± 0.00^{def}
	OV 10	$0.86\pm0.17^{a-e}$	1.12 ± 0.46^{a}	$0.82\pm0.19^{a-f}$	$0.57\pm0.07^{c-f}$	0.44 ± 0.00^{f}	0.47 ± 0.02^{ef}	$0.73\pm0.02^{b-f}$	$0.57\pm0.00^{c-f}$	$0.61\pm0.01^{c-f}$
	OV 20	$0.87\pm0.02^{a-d}$	$0.65\pm0.03^{b-f}$	$0.74\pm0.06^{b-f}$	0.96 ± 0.34^{abc}	0.51 ± 0.01^{def}	0.49 ± 0.03^{def}	0.56 ± 0.02^{def}	$0.72\pm0.13^{b-f}$	$0.58\pm0.03^{c-f}$
	OV 30	$0.88\pm0.02^{a-d}$	$0.71\pm0.03^{b-f}$	$0.78\pm0.04^{a-f}$	$0.57\pm0.02^{c-f}$	0.56 ± 0.01^{def}	$0.64\pm0.04^{b-f}$	$0.65\pm0.01^{b-f}$	$0.64\pm0.01^{b-f}$	$0.76\pm0.02^{a-f}$
Goindoic (C20:1)	Day 0	$0.78\pm0.12^{b-f}$	$0.33\pm0.00^{g-j}$	$0.74\pm0.14^{b-g}$	$0.62\pm0.02^{b-j}$	$0.44\pm0.05^{c-j}$	$0.32\pm0.01^{g-j}$	$0.49\pm0.15^{b-j}$	0.31 ± 0.07^{hij}	$0.67\pm0.03^{b-j}$
	SH 10	$0.60\pm0.03^{b-j}$	$0.49\pm0.22^{b-j}$	$0.58\pm0.02^{b-j}$	0.84 ± 0.15^{bcd}	0.85 ± 0.01^{bc}	$0.63\pm0.00^{b-j}$	$0.62\pm0.00^{b-j}$	$0.71\pm0.16^{b-i}$	$0.72\pm0.14^{b-h}$
	SH 20	$0.55\pm0.06^{b-j}$	$0.50\pm0.01^{b-j}$	$0.50\pm0.03^{b-j}$	$0.47\pm0.02^{b-j}$	$0.60\pm0.04^{b-j}$	$0.49\pm0.01^{b-j}$	$0.56\pm0.04^{b-j}$	$0.54\pm0.07^{b-j}$	$0.49\pm0.01^{b-j}$
	SH 30	$0.42\pm0.02^{d-j}$	$0.59\pm0.20^{b-j}$	$0.32\pm0.05^{g-j}$	$0.49\pm0.05^{b-j}$	$0.33\pm0.00^{g-j}$	0.29 ± 0.00^{ij}	$0.34\pm0.01^{g-j}$	$0.37\pm0.06^{f-j}$	$0.39\pm0.10^{e-j}$
	OV 10	1.34 ± 0.67^{a}	$0.82\pm0.00^{b-e}$	$0.62\pm0.01^{b-j}$	0.87 ± 0.30^{b}	$0.50\pm0.10^{b-j}$	$0.69\pm0.12^{b-j}$	$0.50\pm0.00^{b-j}$	$0.55\pm0.00^{b-j}$	$0.52\pm0.00^{b-j}$
	OV 20	$0.69\pm0.18^{b-j}$	$0.46\pm0.08^{b-j}$	$0.51\pm0.02^{b-j}$	$0.49\pm0.07^{b-j}$	$0.49\pm0.02^{b-j}$	$0.54\pm0.07^{b-j}$	0.29 ± 0.03^{ij}	$0.52\pm0.03^{b-j}$	$0.48\pm0.05^{b-j}$
	OV 30	$0.67\pm0.01^{b-j}$	$0.40\pm0.06^{e-j}$	$0.56\pm0.08^{b-j}$	$0.39\pm0.08^{f-j}$	$0.46\pm0.08^{b-j}$	$0.45\pm0.01^{b-j}$	$0.35\pm0.07^{g-j}$	0.28 ± 0.03^{j}	$0.43\pm0.09^{c-j}$

For each property, values followed by different letters, regardless of the row and column, are significantly different at 5% level by Duncan Multiple Range Test. Storage refers to storage temperature & duration (days), Shelf stored at 25°C (SH), Oven stored at 60°C (OV).

Table 6 (continues)

Table 6: Changes in fatty acids and triterpene in pomegranate kernel oil subjected to different storage temperatures and duration

Property	Storage (days)	Cultivar								
		Wonderful			Acco			Herskovitz		
		Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone
Linoleic (C18:2)	Day 0	7.47±0.74^{b-e}	5.22±0.44^{e}	7.49±1.70^{b-e}	5.85±0.18^{de}	6.04±0.03^{cde}	5.99±0.34^{de}	7.16±0.10^{b-e}	7.46±0.65^{b-e}	6.56±0.03^{b-e}
	SH 10	6.08±0.01^{cde}	7.09±1.69^{b-e}	6.47±0.33^{b-e}	7.70±0.16^{bcd}	6.85±0.01^{b-e}	7.74±0.19^{bcd}	8.10±0.09^{a-d}	7.83±0.45^{a-d}	8.47±0.05^{abc}
	SH 20	6.21±0.04^{cde}	6.94±0.50^{b-e}	5.91±0.15^{de}	7.52±0.24^{b-e}	7.31±0.64^{b-e}	7.55±0.00^{b-e}	8.16±1.10^{a-d}	8.14±0.06^{a-d}	7.58±0.02^{b-e}
	SH 30	6.63±0.01^{b-e}	6.73±0.11^{b-e}	6.38±0.16^{b-e}	7.21±0.40^{b-e}	6.17±0.06^{cde}	6.13±0.10^{cde}	7.83±0.03^{a-d}	8.06±0.21^{a-d}	7.28±0.10^{b-e}
	OV 10	10.13±3.93^{a}	6.42±0.35^{b-e}	7.74±1.45^{bcd}	7.40±0.91^{b-e}	5.82±0.01^{de}	6.21±0.29^{cde}	7.20±0.02^{b-e}	7.23±0.05^{b-e}	7.57±0.13^{b-e}
	OV 20	6.00±0.21^{de}	6.40±0.18^{b-e}	6.69±0.45^{b-e}	7.93±0.07^{a-d}	6.81±0.38^{b-e}	6.36±0.34^{b-e}	6.47±0.28^{b-e}	8.70±1.14^{ab}	6.43±0.53^{b-e}
	OV 30	5.85±0.16^{de}	6.79±0.15^{b-e}	6.57±0.20^{b-e}	6.41±0.15^{b-e}	6.61±0.22^{b-e}	7.14±0.08^{b-e}	6.79±0.03^{b-e}	7.19±0.11^{b-e}	7.66±0.03^{b-e}
Triterpene (squalene)	Day 0	3.34±1.34^{a}	3.16±0.29^{ab}	2.59±0.25^{a-f}	3.12±0.49^{abc}	2.87±0.14^{a-d}	2.56±0.05^{a-f}	1.97±0.12^{d-j}	1.77±0.50^{e-m}	3.14±0.81^{ab}
	SH 10	1.90±0.25^{d-k}	2.12±0.04^{b-h}	1.76±0.09^{e-n}	1.38±0.03^{h-o}	1.41±0.02^{h-o}	1.29±0.02^{h-o}	1.00±0.02^{i-o}	1.00±0.02^{i-o}	0.84±0.01^{k-o}
	SH 20	1.99±0.49^{d-j}	1.56±0.02^{f-o}	1.71±0.14^{e-n}	1.13±0.07^{h-o}	1.58±0.08^{f-o}	0.91±0.12^{j-o}	0.79±0.08^{k-o}	0.56±0.03^{o}	0.90±0.18^{j-o}
	SH 30	2.51±0.10^{a-g}	2.56±0.29^{a-f}	2.08±0.40^{c-i}	1.46±0.20^{g-o}	3.18±0.57^{ab}	2.72±0.74^{a-e}	1.05±0.00^{h-o}	0.85±0.08^{k-o}	1.06±0.39^{h-o}
	OV 10	1.52±0.69^{f-o}	1.84±0.03^{d-l}	1.22±0.39^{h-o}	1.74±0.10^{e-n}	0.79±0.02^{k-o}	1.60±0.08^{f-o}	1.17±0.01^{h-o}	1.07±0.01^{h-o}	0.84±0.00^{k-o}
	OV 20	1.23±0.01^{h-o}	2.13±0.21^{b-h}	1.30±0.18^{h-o}	1.35±0.10^{h-o}	1.07±0.02^{h-o}	1.35±0.09^{h-o}	1.36±0.11^{h-o}	0.68±0.05^{mno}	0.65±0.05^{no}
	OV 30	1.86±0.14^{d-l}	1.78±0.38^{e-m}	1.33±0.26^{h-o}	1.82±0.54^{d-l}	1.44±0.13^{g-o}	0.93±0.06^{j-o}	0.90±0.08^{j-o}	1.12±0.15^{h-o}	0.75±0.23^{l-o}
∑SFA	Day 0	7.45±0.02^{bcd}	5.98±0.63^{d}	6.76±0.99^{bcd}	6.92±0.35^{bcd}	6.91±0.28^{bcd}	7.37±0.01^{bcd}	6.49±0.40^{bcd}	6.86±0.45^{bcd}	7.49±0.22^{bcd}
	SH 10	7.03±0.24^{bcd}	8.21±1.36^{a-d}	7.13±0.25^{bcd}	8.81±0.26^{abc}	7.86±0.06^{a-d}	8.29±0.15^{a-d}	7.24±0.09^{bcd}	7.02±0.44^{bcd}	7.34±0.02^{bcd}
	SH 20	6.60±0.12^{bcd}	6.80±0.13^{bcd}	6.24±0.02^{cd}	7.23±0.13^{bcd}	7.88±0.53^{a-d}	7.19±0.12^{bcd}	6.85±0.29^{bcd}	6.67±0.38^{bcd}	6.54±0.54^{bcd}
	SH 30	7.53±0.01^{bcd}	7.37±0.10^{bcd}	6.61±0.44^{bcd}	7.64±0.54^{bcd}	7.65±0.23^{bcd}	7.50±0.57^{bcd}	7.04±0.09^{bcd}	6.92±0.55^{bcd}	6.38±0.79^{bcd}
	OV 10	10.15±4.41^{a}	7.51±0.29^{bcd}	7.80±2.01^{a-d}	8.83±0.73^{ab}	6.11±0.00^{d}	7.17±0.37^{bcd}	7.29±0.05^{bcd}	7.11±0.07^{bcd}	6.81±0.14^{bcd}
	OV 20	6.61±0.29^{bcd}	6.92±0.16^{bcd}	6.52±0.09^{bcd}	7.51±0.36^{bcd}	7.21±0.05^{bcd}	7.12±0.78^{bcd}	6.24±0.13^{cd}	7.06±0.66^{bcd}	5.80±0.00^{d}
	OV 30	6.88±0.19^{bcd}	7.02±0.47^{bcd}	7.11±0.03^{bcd}	7.44±0.50^{bcd}	7.63±0.35^{bcd}	6.91±0.06^{bcd}	6.53±0.16^{bcd}	6.86±0.07^{bcd}	6.65±0.61^{bcd}

For each property, values followed by different letters, regardless of the row and column, are significantly different at 5% level by Duncan Multiple Range Test. Storage refers to storage temperature & duration (days), Shelf stored at 25°C (SH), Oven stored at 60°C (OV).

Table 6 (continues)

Table 6: Changes in fatty acids and triterpene in pomegranate kernel oil subjected to different storage temperatures and duration

		Cultivar								
		Wonderful			Acco			Herskovitz		
Property	Storage (days)	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone
∑MUFA	Day 0	6.92±1.23^{d-n}	4.45±0.45^{n}	5.97±1.09^{i-n}	6.58±0.53^{f-n}	6.57±0.13^{f-n}	6.74±0.01^{e-n}	5.65±0.03^{k-n}	5.56±0.34^{l-n}	5.44±0.32^{l-n}
	SH 10	5.99±0.21^{i-n}	6.98±2.23^{c-m}	6.19±0.47^{h-n}	9.98±0.12^{a}	8.19±0.00^{a-j}	9.18±0.37^{a-e}	6.98±0.23^{c-m}	7.31±0.74^{b-m}	7.78±0.23^{a-m}
	SH 20	5.56±0.07^{i-n}	6.39±0.41^{g-n}	5.32±0.12^{l-n}	8.68±0.44^{a-h}	8.77±1.07^{a-g}	8.93±0.17^{a-f}	7.36±1.33^{b-m}	8.32±0.22^{a-i}	6.86±0.02^{d-n}
	SH 30	5.78±0.18^{j-n}	5.80±0.38^{j-n}	5.29±0.16^{mn}	7.81±0.44^{a-l}	6.32±0.17^{g-n}	6.35±0.02^{g-n}	6.13±0.02^{i-n}	6.40±0.03^{g-n}	5.81±0.09^{j-n}
	OV 10	9.29±3.24^{a-d}	7.06±0.73^{c-m}	7.42±1.37^{b-m}	9.53±1.46^{ab}	6.91±0.10^{d-n}	7.24±0.21^{b-m}	6.39±0.01^{g-n}	6.44±0.02^{g-n}	6.65±0.18^{f-n}
	OV 20	6.37±0.38^{g-n}	5.71±0.37^{j-n}	6.58±0.50^{f-n}	9.41±0.02^{abc}	8.15±0.34^{a-k}	7.58±0.74^{a-m}	5.49±0.22^{l-n}	8.10±1.20^{a-k}	6.13±0.37^{i-n}
	OV 30	6.01±0.12^{i-n}	5.76±0.02^{j-n}	6.22±0.30^{h-n}	7.16±0.00^{b-m}	7.33±0.13^{b-m}	7.76±0.05^{a-m}	5.97±0.11^{i-n}	6.09±0.02^{i-n}	6.59±0.17^{f-n}
∑PUFA	Day 0	76.90±0.52^{g-j}	80.03±0.59^{a-i}	77.86±2.58^{d-j}	76.14±0.70^{hij}	77.16±0.28^{f-j}	77.00±0.13^{g-j}	78.44±0.61^{c-i}	79.21±0.98^{a-i}	72.28±4.54^{j}
	SH 10	82.08±0.14^{a-h}	78.23±3.75^{d-i}	81.73±0.29^{a-h}	77.81±0.56^{e-j}	80.40±0.11^{a-i}	79.10±0.20^{a-i}	82.56±0.18^{a-g}	81.98±1.13^{a-h}	81.15±0.28^{a-h}
	SH 20	82.59±0.79^{a-g}	81.86±0.70^{a-h}	83.15±0.19^{a-f}	80.74±0.78^{a-i}	78.90±1.79^{a-i}	80.86±0.12^{a-h}	82.69±1.47^{a-g}	82.60±0.83^{a-g}	81.62±1.29^{a-h}
	SH 30	81.46±0.10^{a-h}	80.90±0.78^{a-h}	82.59±1.26^{a-g}	80.73±0.86^{a-i}	78.58±1.16^{b-i}	79.64±1.28^{a-i}	83.56±0.02^{a-e}	83.87±0.75^{a-d}	82.93±2.07^{a-g}
	OV 10	74.83±8.54^{i-j}	80.47±0.86^{a-i}	80.17±4.78^{a-i}	77.12±2.47^{f-j}	84.32±0.13^{abc}	81.44±0.81^{a-h}	82.57±0.05^{a-g}	82.66±0.05^{a-g}	83.08±0.34^{a-f}
	OV 20	83.67±0.38^{a-e}	82.06±0.27^{a-h}	82.55±0.03^{a-g}	78.94±0.54^{a-i}	81.49±0.53^{a-h}	81.23±1.60^{a-h}	82.94±0.78^{a-g}	81.88±1.84^{a-h}	84.93±0.09^{a}
	OV 30	82.66±0.82^{a-g}	83.27±1.33^{a-e}	83.27±0.27^{a-e}	81.41±1.34^{a-h}	81.74±0.57^{a-h}	82.83±0.16^{a-g}	84.50±0.56^{ab}	83.78±0.53^{a-e}	83.85±1.20^{a-e}
∑UFA	Day 0	83.82±1.74^{jk}	84.48±0.14^{g-k}	83.83±1.49^{jk}	82.72±1.23^{k}	83.73±0.41^{jk}	83.74±0.12^{jk}	84.09±0.58^{ijk}	84.77±1.32^{f-k}	77.72±4.86^{l}
	SH 10	88.07±0.07^{a-j}	85.21±1.53^{d-k}	87.92±0.19^{a-j}	87.79±0.68^{a-j}	88.59±0.11^{a-g}	88.28±0.18^{a-i}	89.55±0.06^{a-d}	89.28±0.39^{a-e}	88.93±0.05^{a-g}
	SH 20	88.15±0.86^{a-j}	88.25±0.29^{a-i}	88.48±0.07^{a-i}	89.42±0.33^{a-d}	87.67±0.72^{a-j}	89.80±0.29^{abc}	90.05±0.14^{abc}	90.92±0.61^{ab}	88.48±1.27^{a-i}
	SH 30	87.23±0.08^{a-j}	86.70±1.16^{b-k}	87.88±1.10^{a-j}	88.54±0.42^{a-h}	84.90±1.33^{e-k}	85.99±1.26^{c-k}	89.69±0.00^{a-d}	90.27±0.73^{abc}	88.74±2.15^{a-g}
	OV 10	84.12±5.31^{h-k}	87.53±0.12^{a-j}	87.59±3.41^{a-j}	86.65±1.01^{b-k}	91.23±0.23^{a}	88.68±0.60^{a-g}	88.97±0.04^{a-f}	89.10±0.03^{a-f}	89.73±0.15^{abc}
	OV 20	90.04±0.01^{abc}	87.77±0.10^{a-j}	89.14±0.53^{a-f}	88.34±0.56^{a-i}	89.64±0.19^{a-d}	88.80±0.86^{a-g}	88.43±0.56^{a-i}	89.98±0.64^{abc}	91.06±0.29^{ab}
	OV 30	88.68±0.70^{a-g}	89.03±1.31^{a-f}	89.49±0.57^{a-d}	88.57±1.34^{a-g}	89.06±0.44^{a-f}	90.59±0.11^{ab}	90.48±0.67^{ab}	89.87±0.52^{abc}	90.45±1.37^{abc}

For each property, values followed by different letters, regardless of the row and column, are significantly different at 5% level by Duncan Multiple Range Test. Storage refers to storage temperature & duration (days), Shelf stored at 25°C (SH), Oven stored at 60°C (OV).

Table 6 (continues)

Table 6: Changes in fatty acids and triterpene in pomegranate kernel oil subjected to different storage temperatures and duration

		Cultivar								
		Wonderful			Acco			Herskovitz		
Property	Storage (days)	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone
PUFA/ MUFA	Day 0	11.46±1.96^{b-p}	18.20±1.99^{a}	13.58±2.92^{b-j}	11.64±0.83^{b-p}	11.75±0.19^{b-p}	11.42±0.03^{b-p}	13.87±0.17^{b-h}	14.30±0.70^{a-f}	13.28±0.05^{b-l}
	SH 10	13.73±0.51^{b-i}	12.66±4.57^{b-m}	13.27±1.06^{b-l}	7.80±0.03^{p}	9.82±0.02^{h-p}	8.63±0.37^{m-p}	11.84±0.42^{b-p}	11.35±1.30^{b-p}	10.45±0.34^{e-p}
	SH 20	14.86±0.03^{a-d}	12.87±0.94^{b-m}	15.63±0.39^{ab}	9.33±0.57^{j-p}	9.16±1.32^{k-p}	9.05±0.16^{l-p}	11.66±2.31^{b-p}	9.93±0.36^{g-p}	11.89±0.22^{b-p}
	SH 30	14.12±0.46^{b-g}	14.01±0.79^{b-h}	15.62±0.72^{ab}	10.38±0.70^{e-p}	12.44±0.16^{b-o}	12.55±0.23^{b-o}	13.63±0.05^{b-i}	13.10±0.18^{b-l}	14.27±0.14^{a-f}
	OV 10	9.54±4.24^{i-p}	11.53±1.31^{b-p}	11.30±2.73^{c-p}	8.32±1.54^{op}	12.21±0.15^{b-o}	11.26±0.44^{c-p}	12.92±0.02^{b-l}	12.84±0.05^{b-m}	12.51±0.39^{b-o}
	OV 20	13.19±0.84^{b-l}	14.44±0.99^{a-e}	12.62±0.95^{b-n}	8.39±0.04^{nop}	10.02±0.48^{f-p}	10.84±1.27^{d-p}	15.14±0.75^{abc}	10.37±1.76^{e-p}	13.90±0.86^{b-h}
	OV 30	13.76±0.41^{b-i}	14.47±0.29^{a-e}	13.42±0.60^{b-k}	11.38±0.18^{b-p}	11.16±0.28^{c-p}	10.67±0.09^{d-p}	14.15±0.17^{b-g}	13.76±0.13^{b-i}	12.72±0.15^{b-m}
SFA/ MUFA	Day 0	1.11±0.20^{b-o}	1.34±0.00^{ab}	1.14±0.04^{b-m}	1.05±0.03^{d-p}	1.05±0.02^{d-p}	1.09±0.00^{c-o}	1.15±0.08^{b-k}	1.23±0.00^{a-e}	1.38±0.12^{a}
	SH 10	1.17±0.00^{a-j}	1.24±0.20^{a-e}	1.16±0.05^{a-k}	0.88±0.04^{o-r}	0.96±0.01^{h-r}	0.90±0.02^{m-r}	1.04±0.02^{d-q}	0.96±0.04^{h-r}	0.95±0.02^{i-r}
	SH 20	1.19±0.04^{a-h}	1.07±0.05^{d-p}	1.17±0.02^{a-k}	0.83±0.03^{pqr}	0.91±0.05^{l-r}	0.81±0.03^{qr}	0.95±0.13^{h-r}	0.80±0.02^{r}	0.95±0.08^{h-r}
	SH 30	1.31±0.04^{abc}	1.27±0.07^{a-d}	1.25±0.05^{a-e}	0.98±0.01^{g-r}	1.21±0.07^{a-g}	1.18±0.09^{a-i}	1.15±0.01^{b-k}	1.08±0.08^{c-o}	1.10±0.15^{c-o}
	OV 10	1.06±0.11^{d-p}	1.07±0.07^{c-o}	1.04±0.08^{e-q}	0.94±0.07^{k-r}	0.88±0.01^{o-r}	0.99±0.02^{f-r}	1.14±0.01^{b-l}	1.10±0.01^{c-o}	1.02±0.01^{e-r}
	OV 20	1.04±0.11^{d-p}	1.21±0.05^{a-g}	1.00±0.09^{f-r}	0.80±0.04^{r}	0.89±0.04^{o-r}	0.94±0.01^{j-r}	1.14±0.02^{b-m}	0.88±0.05^{o-r}	0.95±0.06^{i-r}
	OV 30	1.14±0.01^{b-k}	1.22±0.08^{a-f}	1.15±0.05^{b-k}	1.04±0.07^{d-q}	1.04±0.03^{d-q}	0.89±0.01^{m}	1.09±0.05^{c-o}	1.13±0.01^{b-n}	1.01±0.12^{e-r}
SFA/ PUFA	Day 0	0.10±0.00^{bcd}	0.07±0.01^{bcd}	0.09±0.02^{bcd}	0.09±0.00^{bcd}	0.09±0.00^{bcd}	0.10±0.00^{bcd}	0.08±0.00^{bcd}	0.09±0.00^{bcd}	0.10±0.01^{bcd}
	SH 10	0.09±0.00^{bcd}	0.11±0.02^{bcd}	0.09±0.00^{bcd}	0.11±0.00^{abc}	0.10±0.00^{bcd}	0.10±0.00^{bcd}	0.09±0.00^{bcd}	0.09±0.01^{bcd}	0.09±0.00^{bcd}
	SH 20	0.08±0.00^{bcd}	0.08±0.00^{bcd}	0.08±0.00^{bcd}	0.09±0.00^{bcd}	0.10±0.01^{bcd}	0.09±0.00^{bcd}	0.08±0.01^{bcd}	0.08±0.01^{bcd}	0.08±0.01^{bcd}
	SH 30	0.09±0.00^{bcd}	0.09±0.00^{bcd}	0.08±0.01^{bcd}	0.09±0.01^{bcd}	0.10±0.00^{bcd}	0.09±0.01^{bcd}	0.08±0.00^{bcd}	0.08±0.01^{bcd}	0.08±0.01^{bcd}
	OV 10	0.14±0.08^{a}	0.09±0.00^{bcd}	0.10±0.03^{bcd}	0.11±0.01^{ab}	0.07±0.00^{cd}	0.09±0.01^{bcd}	0.09±0.00^{bcd}	0.09±0.00^{bcd}	0.08±0.00^{bcd}
	OV 20	0.08±0.00^{bcd}	0.08±0.00^{bcd}	0.08±0.00^{bcd}	0.10±0.01^{bcd}	0.09±0.00^{bcd}	0.09±0.01^{bcd}	0.08±0.00^{bcd}	0.09±0.01^{bcd}	0.07±0.00^{d}
	OV 30	0.08±0.00^{bcd}	0.08±0.01^{bcd}	0.09±0.00^{bcd}	0.09±0.01^{bcd}	0.09±0.00^{bcd}	0.08±0.00^{bcd}	0.08±0.00^{bcd}	0.08±0.00^{bcd}	0.08±0.00^{bcd}

For each property, values followed by different letters, regardless of the row and column, are significantly different at 5% level by Duncan Multiple Range Test. Storage refers to storage temperature & duration (days), Shelf stored at 25°C (SH), Oven stored at 60°C (OV).

Table 6 (continues)

Table 6: Changes in fatty acids and triterpene in pomegranate kernel oil subjected to different storage temperatures and duration

		Cultivar								
		Wonderful			Acco			Herskovitz		
Property	Storability	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone	Hexane	Petroleum ether	Acetone
SFA/UFA	Day 0	0.09 ± 0.00^{bcd}	0.07 ± 0.01^{bcd}	0.08 ± 0.01^{bcd}	0.08 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}	0.09 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}	$0.10\pm0.01^{a-d}$
	SH 10	0.08 ± 0.00^{bcd}	$0.10\pm0.02^{a-d}$	0.08 ± 0.00^{bcd}	0.10 ± 0.00^{abc}	0.09 ± 0.00^{bcd}	$0.09\pm0.00^{a-d}$	0.08 ± 0.00^{bcd}	0.08 ± 0.01^{bcd}	0.08 ± 0.00^{bcd}
	SH 20	0.07 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}	0.07 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}	0.09 ± 0.01^{bcd}	0.08 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}	0.07 ± 0.00^{bcd}	0.07 ± 0.01^{bcd}
	SH 30	0.09 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}	0.08 ± 0.01^{bcd}	0.09 ± 0.01^{bcd}	0.09 ± 0.00^{bcd}	0.09 ± 0.01^{bcd}	0.08 ± 0.00^{bcd}	0.08 ± 0.01^{bcd}	0.07 ± 0.01^{bcd}
	OV 10	0.12 ± 0.06^{a}	0.09 ± 0.00^{bcd}	0.09 ± 0.03^{bcd}	0.10 ± 0.01^{ab}	0.07 ± 0.00^{cd}	0.08 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}
	OV 20	0.07 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}	0.07 ± 0.00^{bcd}	0.09 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}	0.08 ± 0.01^{bcd}	0.07 ± 0.00^{bcd}	0.08 ± 0.01^{bcd}	0.06 ± 0.00^{d}
	OV 30	0.08 ± 0.00^{bcd}	0.08 ± 0.01^{bcd}	0.08 ± 0.00^{bcd}	0.08 ± 0.01^{bcd}	0.09 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}	0.07 ± 0.00^{bcd}	0.08 ± 0.00^{bcd}	0.07 ± 0.01^{bcd}
Index of atherogenicity	Day 0	0.05 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.01^{b}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.05 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.05 ± 0.01^{b}
	SH 10	0.04 ± 0.00^{b}	0.06 ± 0.02^{ab}	0.04 ± 0.00^{b}	0.06 ± 0.00^{ab}	0.05 ± 0.00^{b}	0.05 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}
	SH 20	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.05 ± 0.00^{b}	0.05 ± 0.01^{b}	0.04 ± 0.00^{b}	0.04 ± 0.01^{b}	0.04 ± 0.01^{b}	0.04 ± 0.00^{b}
	SH 30	0.05 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.05 ± 0.00^{b}	0.05 ± 0.00^{b}	0.05 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.01^{b}
	OV 10	0.07 ± 0.04^{a}	0.05 ± 0.00^{b}	0.05 ± 0.02^{b}	0.06 ± 0.01^{ab}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.05 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}
	OV 20	0.05 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.05 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.01^{b}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}
	OV 30	0.05 ± 0.00^{b}	0.05 ± 0.00^{b}	0.05 ± 0.00^{b}	0.05 ± 0.00^{b}	0.05 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.05 ± 0.00^{b}
Index of thrombogenicity	Day 0	0.03 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.03 ± 0.00^{bc}
	SH 10	0.02 ± 0.00^{bc}	0.03 ± 0.01^{abc}	0.02 ± 0.00^{bc}	0.03 ± 0.00^{abc}	0.03 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}
	SH 20	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}
	SH 30	0.03 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}
	OV 10	0.04 ± 0.02^{a}	0.03 ± 0.00^{bc}	0.03 ± 0.01^{bc}	0.03 ± 0.00^{ab}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.03 ± 0.00^{bc}
	OV 20	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{c}
	OV 30	0.03 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}

For each property, values followed by different letters, regardless of the row and column, are significantly different at 5% level by Duncan Multiple Range Test. Storage refers to storage temperature & duration (days), Shelf stored at 25°C (SH), Oven stored at 60°C (OV).

Table 7: Factor scores, Eigen value, variance (%) and cumulative variance (%) for factors based on oil properties of Wonderful, Acco and Herskovitz pomegranate cultivars

Observation	F1	F2	F3	F4	F5	F6	F7	F8
Wonderful_Hex	0.916	-1.110	5.589	-0.933	1.483	-0.366	0.292	-0.235
Wonderful_Pet	-6.320	4.336	-1.351	0.284	2.230	-0.881	-0.538	-0.153
Wonderful_Ace	1.813	2.289	1.052	5.091	-1.009	0.802	-0.192	0.107
Acco_Hex	-0.537	-3.648	-1.888	0.823	1.332	0.218	1.705	0.916
Acco_Pet	-1.669	-4.717	-0.811	-0.527	0.297	2.018	-1.505	-0.314
Acco_Ace	1.972	-3.344	-1.233	0.629	-1.062	-2.842	-0.461	-0.519
Herskovitz_Hex	-2.252	1.504	-0.551	-1.352	-1.859	0.847	1.352	-1.239
Herskovitz_Pet	-2.385	1.409	0.914	-2.089	-2.363	-0.238	-0.421	1.373
Herskovitz_Ace	8.462	3.282	-1.721	-1.925	0.951	0.442	-0.233	0.063
Eigen value	14.822	9.671	4.890	4.236	2.348	1.636	0.873	0.525
Variance (%)	38.005	24.797	12.539	10.860	6.020	4.194	2.238	1.345
Cum. variance (%)	38.005	62.803	75.342	86.202	92.222	96.417	98.655	100.000

Petroleum ether (Pet), *n*-hexane (Hex), Acetone (Ace).

Table 8: Factor loadings for factors based on oil properties of Wonderful, Acco and Herskovitz pomegranate cultivars

Observation	F1	F2	F3	F4	F5	F6	F7	F8
Yield	-0.138	-0.902	-0.373	-0.057	0.008	0.069	0.051	0.129
Refractive index	-0.072	0.829	0.530	0.112	0.091	0.053	0.008	-0.055
Conjugated dienes	-0.490	-0.212	-0.692	0.322	-0.217	0.095	0.255	0.108
Conjugated trienes	0.264	0.176	-0.343	0.733	0.084	-0.229	0.295	0.313
p-Anisidine value	0.727	0.285	-0.069	-0.160	-0.266	-0.288	0.393	-0.229
Total phenolic content	0.788	-0.197	-0.564	0.062	-0.068	0.065	0.062	-0.077
Total carotenoids content (440 nm)	0.165	0.958	-0.112	0.014	0.032	-0.103	0.107	0.137
Total carotenoids content (460 nm)	-0.137	0.905	0.035	-0.266	-0.075	-0.152	0.204	0.139
DPPH	0.381	0.306	-0.059	-0.580	-0.243	0.595	-0.030	-0.082
Palmitic	0.839	0.290	0.321	-0.112	-0.292	0.023	-0.009	0.101
Stearic	0.358	-0.835	0.166	-0.129	0.284	-0.220	-0.026	0.016
Arachidic	0.632	-0.123	-0.094	-0.445	-0.438	-0.286	-0.277	0.170
Oleic	0.129	-0.956	0.112	0.082	-0.183	-0.120	0.024	-0.035
Vaccenic	0.320	0.174	0.892	-0.187	0.166	-0.038	0.072	-0.054
Goindoic	0.552	0.045	0.474	0.316	0.303	0.383	0.360	-0.023
Linoleic	0.276	0.197	0.680	0.007	-0.573	0.252	0.159	0.075
Punicic	-0.921	-0.209	-0.123	-0.297	0.015	0.041	-0.048	-0.019
α-Linolenic	0.495	0.461	0.280	0.507	-0.118	-0.429	-0.043	0.081
γ-Linolenic	0.276	0.275	-0.155	0.879	-0.015	-0.123	-0.110	-0.157
Triterpene (squalene)	0.240	-0.123	0.085	0.126	0.948	-0.019	-0.050	-0.049
Tocol (γ-tocopherol)	0.740	0.273	-0.486	-0.328	-0.079	0.155	-0.012	0.067
Phytosterol (γ-sitosterol)	0.595	0.569	-0.354	-0.210	0.245	0.276	0.083	0.102
∑SFA	0.812	-0.416	0.297	-0.200	-0.022	-0.167	-0.051	0.088
∑MUFA	0.303	-0.859	0.365	0.118	-0.074	-0.031	0.118	-0.048
∑PUFA	-0.909	0.126	0.170	0.182	-0.268	-0.132	-0.080	-0.016
∑UFA	-0.832	-0.190	0.314	0.234	-0.306	-0.149	-0.040	-0.034
PUFA/MUFA	-0.512	0.802	-0.228	0.000	0.135	-0.056	-0.145	0.024
SFA/MUFA	0.154	0.857	-0.207	-0.306	0.202	-0.106	-0.203	0.115
SFA/PUFA	0.908	-0.306	0.152	-0.203	0.083	-0.078	-0.023	0.069
SFA/UFA	0.922	-0.240	0.127	-0.235	0.086	-0.079	-0.037	0.079
Index of atherogenicity	0.948	-0.194	0.201	-0.090	0.073	-0.084	-0.012	0.061
Index of thrombogenicity	0.929	-0.258	0.195	-0.125	0.091	-0.077	-0.007	0.060
Lightness, *L**	-0.783	-0.104	0.145	-0.516	0.206	-0.136	0.108	0.126
Redness, *a**	0.321	0.234	-0.493	-0.524	-0.017	-0.447	0.162	-0.312
Yellowness, *b**	-0.790	-0.046	0.066	-0.523	0.101	-0.199	0.216	0.028
Chroma, *C**	-0.768	-0.033	0.041	-0.549	0.104	-0.213	0.223	0.020
Hue, h^0	-0.855	-0.311	0.351	-0.102	0.000	0.116	0.111	0.114

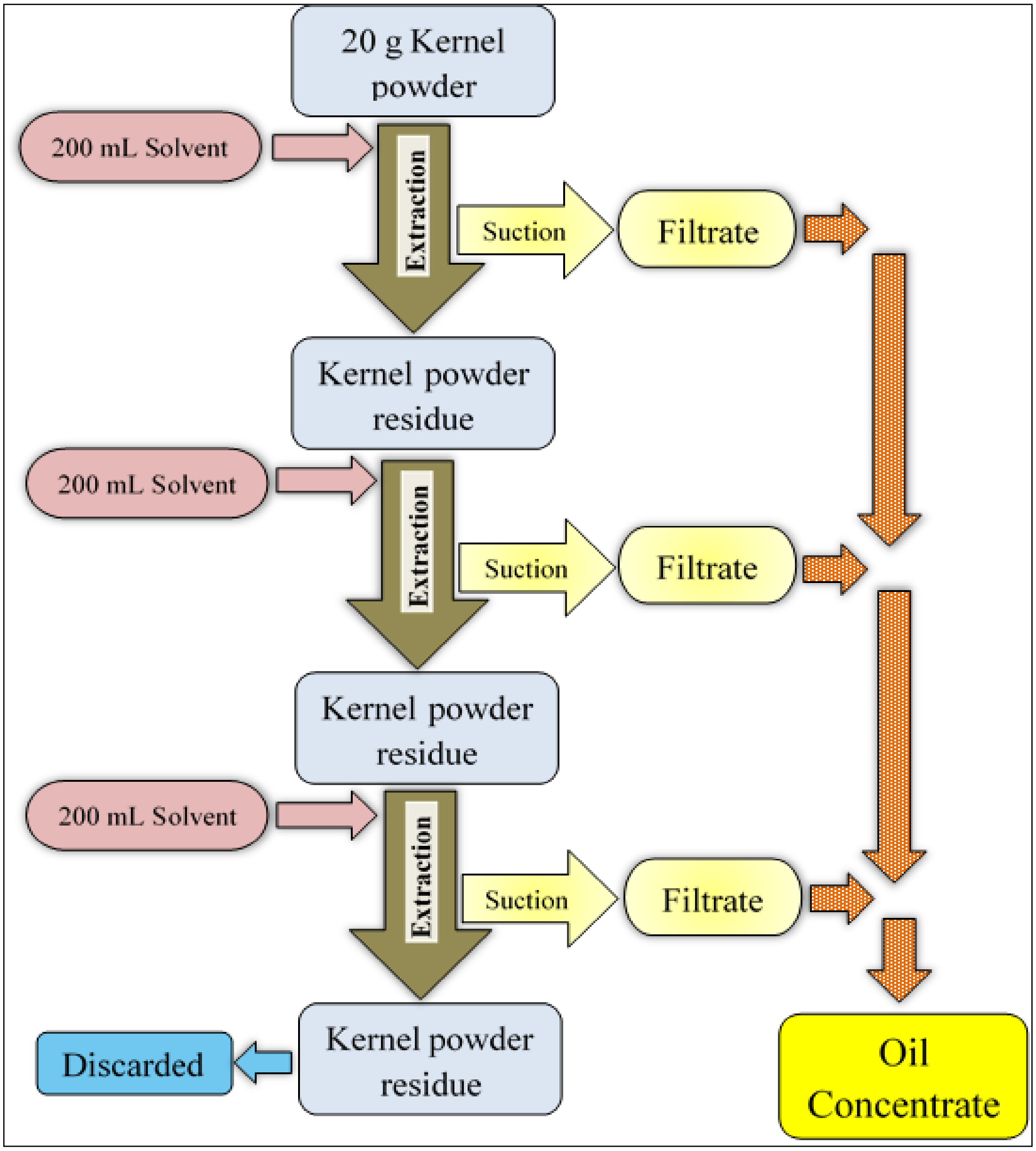

Fig. 1. Stepwise process employed in the extraction of pomegranate kernel oil

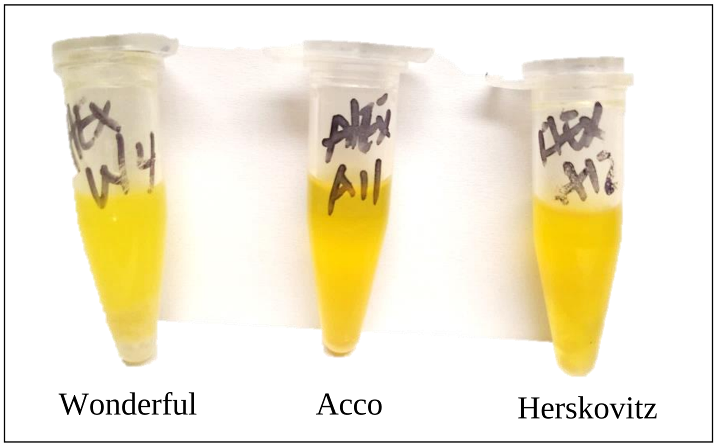

Fig. 2A. Kernel oil extracted from different pomegranate cultivars using *n*-hexane solvent

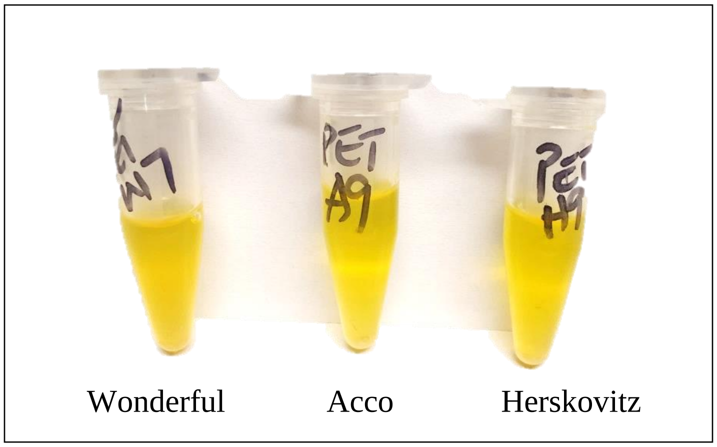

Fig. 2B. Kernel oil extracted from different pomegranate cultivars using petroleum ether solvent

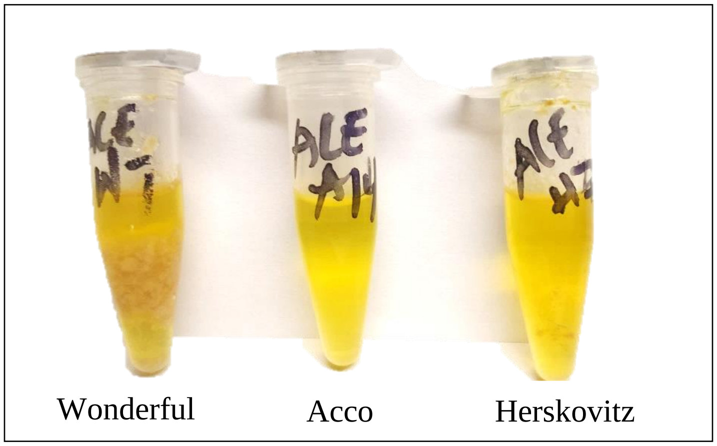

Fig. 2C. Kernel oil extracted from different pomegranate cultivars using acetone solvent