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Composition of Bioactive Compounds from Potato Peel Waste Extracts by Decoction and Indirect Ultra-Sound Assisted Extraction Methods

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Abstract

Purpose: The aim of this study was to obtain potato peel extracts by a conventional, "decoction (DT)" and novel, "indirect ultra-sound assisted extraction (DuAE)" methods, and determine the composition of potato peel extracts in bioactive compounds.

Materials and Methods: To obtain peels extracts, both DT and DuAE extraction methods were used to extract bioactive compounds from peel wastes of five potato cultivars i.e. Kinigi, Kuruseke, Kirundo, Peco, and T58, locally grown in Rwanda. Four types of bioactive compounds, i.e. glycolakaloids (TGC), total phenolics (TPC), total flavonoids (TFC), and total anthocyanins (TAC) were determined in each potato peel extract. Data in concentration of bioactive compounds was subjected to a two factor ANOVA ($p \leq 0.05$) to determine the effect of potato cultivars and extraction methods on the content of bioactive compounds.

Findings: Results showed that the composition ranges of bioactive compounds were 0.47- 11.83 mg SE/100g, 60.12 - 1170.01 mg GAE/100g, 50.39- 873.26 mg QE/100g, and 0.71- 8.73 mg CGE/100 g per dry weight for TGC, TPC, TFC, and TAC, respectively. The composition of bioactive compounds in potato peel extracts was significantly ($p<0.001$) affected by both potato cultivar and extraction method. Generally, potato peel extracts from Kirundo and Kuruseke cultivars had the lowest and the highest amount of bioactive compounds, respectively; whereas the DuAE method performed better than DT method.

Implications to Theory, Practice and Policy: Results from this study revealed the significant role of extraction methods used for bioactive compounds. An investigation on the optimization and improvement of extraction processes used in this study was recommended.

Keywords: *Bioactive Compounds, Extraction Methods, Potato Peel Wastes*

1.0 INTRODUCTION

The potato, scientifically known as *Solanum tuberosum L*., is the third most significant food crop globally (International Potato Center (CIP), 2020). It has a crucial role in the economic growth of developing nations (Hill *et al*., 2021). It contributes to global food security (Campos & Ortiz, 2020). According to Campos and Ortiz (2020), approximately 1.3 billion people worldwide rely on this crop a staple food. Potatoes are consumed immediately after being processed into different products such as French fries, chips, crisps, starch, puree, etc. (Al-Weshahy & Rao, 2009; Jimenez-Champi et al., 2023a). Globally, the demand of processed potato products increases as a result of the shift to processed potato products (Singh *et al*., 2020). Processed potato are gaining an important global market shares with a projection of 4.05% between 2020 and 2026 of processed foods (Global Monitor, 2020)

However, processing of potatoes is associated with generating large quantity of potato peels (Jimenez-Champi et al., 2023a; Susarla, 2019; Venturi et al., 2019). For example, one tonne of potatoes can generate a solid waste of 90-160 kg (Calcio Gaudino *et al*., 2020; Pathak *et al*., 2018). The 15 to 40% of that quantity are potato peels (Sepelev & Galoburda, 2015). The global production estimate for the year 2020 was 143.6 million tonnes of potato residues (Oleszek *et al*., 2023). The volume of potato peel wastes from industry will be around 8000 kilotonnes by 2030 (Khanal *et al*., 2023). With that huge volume of potato peel wastes, it is unfortunate that potato peels is considered as a valueless by-product (Pacifico et al., 2021a). It is a serious handling challenge and burden for potato processors, who generally dispose them of into the environment (Silva-Beltran *et al*., 2017; Joly *et al*., 2021), that contributes to greenhouse gas emissions. Alarmingly, the global estimate of potato peel wastes- gas emissions will be around 5 million tonnes of CO_2 gas equivalent in 2030 (Khanal *et al*., 2023).

Despite the negative impact on the environment, potato peels are however rich in different beneficial nutrients (Al-Weshahy & Rao, 2009; Susarla, 2019). Potato peel wastes are amongst important wastes that can be valorized into different products (Pathak *et al*., 2018). They can be extracted into natural antioxidants i.e. bioactive compounds (Jimenez-Champi *et al*., 2023). For example, almost half of phenolic compounds are found in the peel and neighbouring tissues (Rodríguez-Martínez *et al*., 2021). Potato peel waste is an excellent substrate for extraction of different types of bioactive compounds i.e. dietary fibre, glycoalkaloids and phenolic compounds (Jimenez-Champi *et al*., 2023).

Thus, there is a vital need to extract potato peel wastes into bioactive compounds extracts for several reasons. Particularly, there is a need to respond to emerging agro-food systems issues, which are related to environmental management and circular economy (Gonçalves & Maximo, 2023; Ogbu & Okechukwu, 2023). First, adding value to potato peel wastes responds to the target goal 'substantial reduction of waste generation through prevention, reduction, recycling and reuse' of the 12th Sustainable Development Goal "Responsible consumption and production" of the United Nations Agenda-2030 (United Nations, 2015). Second, it responds to a trending paradigm shift from traditional practices to agricultural bio-economy and circular economy through agro-industrial wastes management (Ogbu & Okechukwu, 2023). Third, it responds to a growing interest in bioactive compounds by consumers, food and pharmaceutical industries for different applications (Jimenez-Champi *et al*., 2023; Khanal *et al*., 2023; Rowayshed *et al*., 2015; Singh *et al*., 2020; Tajner-Czopek *et al*., 2021).

Nevertheless, the composition of bioactive compounds from potato peel extracts are affected by different factors, among others, there are phenotypic characteristics of potato variety, and extraction method and type of solvent used for extraction (Calcio Gaudino *et al*., 2020; Kondamudi *et al*., 2017; Uwineza & Waśkiewicz, 2020; Wang *et al*., 2020). Extraction methods of bioactive compounds are either conventional (pressing, decoction, etc) or novel methods (supercritical fluid extraction, Ultrasound assisted extraction, etc) (Azmir *et al*., 2013; Calcio Gaudino *et al*., 2020; de Andrade Lima *et al*., 2021; Kaneria *et al*., 2012). The conventional method like decoction is known for its simple principle of boiling medicinal plant materials to extract water-soluble and thermostable substances (Manousi *et al*., 2019). The novel method, like the indirect ultra-sound assisted extraction is known advantageous for its extraction efficiency by using sonic waves at lower temperatures to keep the nature bioactive compounds (Jimenez-Champi et al., 2023; Manousi et al., 2019).

However, a little information is known on the extraction of potato peels wastes into bioactive compounds extracts by using those two extraction methods. Therefore, this study evaluated the effectiveness of the extraction of potato peel wastes into bioactive compounds extracts by the use of the decoction and indirect ultra-sound assisted extraction methods and different potato varieties. The present study was expected to reveal the information and provide knowledge on performance of traditional and novel extraction methods of bioactive compounds from potato peel wastes. In the aspect of the valorization of agro-wastes, understanding processes of extraction methods studied could be beneficial to the agro-processing sector for further industrial applications of bioactive compounds.

2.0 MATERIAL AND METHODS

Raw Materials

Potato tubers of five Rwandan potato cultivars i.e. *Kningi*, *Peco*, *Kuruseke*, *Kirundo* and *T58* were used in this study. Potato tubers of each potato cultivar were obtained from Rwanda Agriculture Board (RAB)-Musanze station, in Musanze District, Rwanda. For each potato cultivar, a sample of 10 kg of mature and fresh potato tubers was collected in a woven polyethylene bag and transported to the laboratory for processing. Table 1 shows different characteristics of potato cultivars samples collected. Samples collected were transported to the laboratory for processing. The samples were stored in a dark cabinet at temperatures of 8-10 ^{o}C (Datir *et al*., 2020).

Table 1: Name, Maturity Period, Skin and Flesh Colour of Potato Cultivars

Name	Maturity period (days)	Tuber skin colour	Tuber flesh colour
T58	90-100	White	White
Kinigi	120-135	Red	Light yellow
Kuruseke	120-130	Red	Light yellow and purple
Peco	90-100	Yellow and red-splashed	White
Kirundo	100-110	White	Light yellow flesh

Chemicals, Reagents and Consumables Acquisition

Chemical and reagents were obtained from different companies. Deionized water (DUPHAR Ltd, Rwanda); ethanol 96% (Merck, Darmstadt, Germany); Folin-Ciacolteu reagent (Sigma-Aldrich Inc, USA); Na_2CO_3 (Griffchem Ltd, India), Gallic acid (Sigma-Aldrich Inc, USA); $NaNO_2$

(Griffchem Ltd, India), AlCl3 (Merck, Darmstadt, Germany); NaOH-4% (Griffchem Ltd, India); Quercetin analytical standard (Sigma-Aldrich Inc, USA), Cyanidin-3-glucoside chloride (Sigma-Aldrich Inc, USA); acetic acid, ammonia (NH_3), phosphoric acid, - formic acid, paraformaldehyde; Alpha-solanine, ≥ 95% (Sigma-Aldrich Inc, USA), - Whatman paper Grade 1, 11 µm (Schimandzu Ltd, China)

Preparation of Potato Peel Samples

Potato tubers of each sample were screened to remove tubers with defects and greenish colour. Then, potato samples were prepared following the method of Friedman *et al*. (2018) with some modifications. Potato tubers were subjected to a manual washing under running tap water (18-20 °C) for 2 min per potato tuber to remove the soil, air-dried on an absorbent tissue paper, and manually peeled with a domestic vegetable peeler (Household potato peeler, Ouyamei, China). Before drying, potato peels of each sample were weighed for data records, and chopped into small pieces of about 1cm ×1cm. Drying was done in a forced draft air oven (Model: HDH/750/SS/250/DIG, Leader Engineering Co. Ltd, UK) at 45°C for 24 hours, whereby obtained peels were spread on two stainless steel drying plates. After drying, potato peels were weighed again for data records, powdered using an electric blender and sieved using a kitchen mesh of 0.5mm pore size.

Preparation of Potato Peel Extracts

Potato peel extracts were processed through using two methods of extraction, namely the decoction (DT) as a traditional technique, and the indirect ultrasound-assisted extraction (DuAE), as a novel method. The DT was carried out following the method of Kaneria *et al.* (2012) with minor modifications. Briefly, 5 g potato peel powder was extracted with 100 ml of deionized water at 35°C for 15 min in a water bath (Grant Model, Type GR 150, UK). The mixture was vacuum-filtered by using a Whatman paper, grade 1 (11µm particle size), and the filtrate was centrifuged at 2,800 ×g for 10 min. On another side, the DuAE consists of extracting the substrate in a container by using ultrasonic waves in a water bath. It was done following the method of Riciputi *et al*. (2018) with modifications. Ten (10) gram of potato peel powder was extracted with 100ml of deionized water/ethanol solvent (45%V/55%V) by sonication in a ultrasonic bath (Branson 3510, Branson Ultrasonic Corp., USA) for 35 min at 35 °C. After sonication, the mixture was vacuum-filtered by using Whatman No.1 paper (11µm of particle size). After extraction, the concentrate extracts were stored at -20 °C before drying and determining the content of bioactive compounds. The drying process of supernatant and filtrates extracts from DT and DuAE extraction methods, respectively, was done through removing extraction solvents using a vacuum rotary evaporation system (Model: ROVA-100S, MRC Laboratory Equipments & Instruments LTD, Israel).

Determination of the Composition of Bioactive Compounds

Total phenolic content (TPC): the method of Folin-Ciacolteu as described by Silva-Beltran *et al*. (2017) was adopted with minor modifications. Peel extract of 20 µl was mixed with 1 ml 1 N Folin-Ciocalteu reagent (1:10) for 5 min of equilibration, and 80 µl of Na_2CO_3 (7.5% (w/v)) was added to the mixture and followed by incubation for 20 min at room temperature (≈ 23°C). After incubation, the absorbance was read at 765 nm with a UV-Vis spectrophotometer (Shimadzu model UV – 1800 PC, Kyoto, Japan). The standard curve of gallic acid was plotted by serial dilutions at 0, 5, 10, 20, 30, 40 ,50, 100, 120 mg/ml of gallic standard. The results in TPC of

samples were expressed as milligram of gallic acid equivalent (GAE) per 100 g potato peel powder. The experiment was done in triplicates for each extract sample.

Total flavonoids content (TFC): the method described by Friedman et al. (2017) was adopted. Potato peel extract (1ml) was placed in a 50 ml volumetric flask. Then, several reagents were added in the following sequence: 8 ml of ethanol (60%) followed by 0.2 ml $NaNO_2$ (5%); after 6 min, 0.2 ml AlCl3 (10%); after another 6 min, 0.6 ml NaOH (4%) and distilled water to a volume of 10 ml. The mixture was vortexed for 30 seconds, and the absorbance was read at 415 nm using a spectrophotometer (Shimadzu model UV – 1800 PC, Kyoto, Japan). The standard curve of quercetin was plotted from serial dilutions at 0, 0.1, 0.2, 0.4, 0.6, 0.8, 1 mg/ml of quercetin analytical standard. Total flavonoid content was expressed as milligram of quercetin equivalent (QE) per 100 g dried potato peel powder. The experiment was done in triplicates for each extract sample.

Total anthocyanin content (TAC): the method of Ndungutse (2019) was followed to determine TAC. Potato peel extract of 1 ml was diluted with 20 ml deionized water. From the diluted aliquot, 0.5 ml was pipetted and homogenized with 4 ml of 10% formic acid (1:9v/v). The absorbance was read at 530 nm in a spectrophotometer (Shimadzu model UV – 1800 PC, Kyoto, Japan). For each potato peel sample, the experiment was done in triplicates. The amount of anthocyanin was obtained by the equation (1), and the results were expressed as cyanidin-3-glucose equivalent (CGE) per 100 g potato peel powder. The experiment was done in triplicates for each extract sample.

TAC (mg/100 g of dry weight) = A × MW × DF × 100/(ε × W) (as Cyanidin 3-glucoside, mg/l).....(2)

Where, A = absorbance, MW = molecular weight of Cyanidin 3-glucoside ($C_{21}H_{21}ClO_{11}$, 449.2), DF = dilution factor, ε = molar absorptivity of Cyanidin 3-glucoside (26900), and W = weight of the sample.

Total glycoalkaloids content (TGC): the determination of TGC in potato peel extracts was carried out using the method of Zarzecka *et al*. (2013) with some adjustments. In a centrifuge tube, 5 ml potato peel extracts were added to 50 ml acetic acid (10%). The mixture was centrifuged in a centrifuge (Nüve, Model NF1200R, Turkey) at 3000 ×g for 5 min. The supernatant and sediment were poured into a flask followed by the addition of 4 ml of ammonia (NH_3) to adjust the pH to 10. The flask was heated in a water bath (70 °C) for 20 min, and allowed to cool at 4° C for 3 hours, the mixture was centrifuged at 3000 ×g for 5 min. Then, the sediment was homogenized in 5 ml phosphoric acid (7%). Thereafter, 0.2 ml of the solution was mixed with 2 ml of phosphoric acid (85%) with paraformaldehyde (30 mg/l) and mixed again. After 40 min, the absorbance was read at the wavelength of 600 nm with a spectrophotometer (Shimadzu model UV – 1800 PC, Kyoto, Japan). The quantity of total glycoalkaloids in samples were obtained by using the α-solanine standard curve, which was plotted from serial dilutions at 0, 5, 10, 20, 30, 40, 60 µg/ml of α-solanine standard. The results were expressed as milligram of α-solanine equivalent (SE) per 100 g of potato peel powder. The experiment was done in triplicates for each extract sample.

Data Analysis

Raw data of concentration of TPC, TFC, TAC and TGC from laboratory experiment were subjected to statistical analysis. Two factors analysis of variance (ANOVA) with the General Linear Model (GLM) procedure was performed to show the effects of extraction method and potato

cultivar. The Tukey's test was also performed to separate means at 5% level of significance. The Statistical Analysis System (SAS version 9.3).

3.0 FINDINGS

In this study, results and discussion on the composition of bioactive compounds were reported per the effects of potato cultivar, extraction method and their interaction, respectively.

Effect of Potato Cultivar on the Composition of Bioactive Compounds

Results

Table 2 shows the concentration ranges of bioactive compounds from peel extracts of studied potato cultivars. The composition of peel extracts in studied bioactive compounds varied with potato cultivar. Results ranges 0.97–11.83 mg SE/100g for TGC, 360.96– 856.43 mg GAE/100g for TPC, 356.80–585.58 mg QE/100g for TFC, and 3.28–5.74 mg CGE/100g for TAC. The concentration of TGC was lower and higher in potato peel extracts from Kuruseke (0.97mg SE/100g) and Kinigi (11.83 mg SE/100g) potato cultivars, respectively. The concentrations of TPC, TFC and TAC were lower and higher in potato peel extracts from potato cultivars Kirundo (356.80 mg GAE, 360.96 mg QE and 3.28mg CGE)/100g and Kuruseke (585.58 mg GAE, 856.43 mg QE and 5.74mg CGE)/100g, respectively. The concentration of bioactive compounds in potato peel extracts was very significantly ($p< 0.0001$) affected by potato cultivar.

Table 2: Concentration of Bioactive Compounds in Peel Extracts from Different Potato Cultivars

Potato cultivar	TGC (mg SE/100g)	TPC (mg GAE/100g)	TFC (mg QE/100g)	TAC (mg CGE/100g)
T58	5.02 ± 0.52^{c}	622.38 ± 25.23^{c}	434.92 ± 17.23^{d}	4.62 ± 1.79^{d}
Kinigi	11.83 ± 2.66^{a}	571.26 ± 23.54^{d}	449.87 ± 17.50^{c}	5.20 ± 2.04^{b}
Kuruseke	0.97 ± 0.12^{e}	856.43 ± 33.51^{a}	585.58 ± 23.89^{a}	5.74 ± 2.11^{a}
Peco	4.10 ± 0.18^{d}	664.29 ± 27.92^{b}	481.97 ± 18.20^{b}	4.76 ± 1.84^{c}
Kirundo	11.24 ± 2.15^{b}	360.96 ± 14.72^{e}	356.80 ± 14.20^{e}	3.28 ± 1.20^{e}

Results values are mean ± SD (n=3) determined on dry weight basis of samples. Super scripts (a, b, c, d, and e) on values indicate the difference ($P\leq 0.05$) of obtained results. In each column, values with the same superscript letter are not different, whereas values with different superscripts letters are different.

Discussion

The values of bioactive compounds in Table 2 were influenced by characteristics of potato cultivars studied. In this study, five potato cultivars used (Table 1) to obtain potato peels and process peel extracts were of different morphological characteristics (skin colour, flesh colour) and genetic traits (maturity period). It is worth to note that genetic characteristics and pre/post-harvesting conditions of potato tubers have an effect on the content of glycoalkaloids and phenolic compounds (Akyol *et al*., 2016; Arun *et al*., 2015; Ezekiel *et al*., 2013; Friedman *et a*l., 2018; Kipkoech *et al*., 2018; Palos-Hernández *et al*., 2022; Rasheed *et al*., 2022). Moreover, genetic traits have higher effect on bioactive compounds than the environment (De Masi *et al*., 2020). Therefore, the influence of potato cultivar on the composition of bioactive compounds from potato

peel extracts may be due to several factors of potato tubers. The reported factors are tuber maturity, mechanical injury, skin colour and greening (Akyol *et al*., 2016; Arun *et al*., 2015; Dhalsamant *et al*., 2022; Ezekiel *et al*., 2013; Friedman *et al*., 2018; Kipkoech *et al*., 2018; Palos-Hernández *et al*., 2022; Rasheed *et al*., 2022; Schieber & Saldaña, 2009).

With regard to potato tubers skin colour, results from this study showed that potato cultivars with red-skin colour (Kuruseke) and yellow red-splashed skin colour (Peco) had higher level of phenolic compounds than ones with white skin colour (Kirundo and T58) with exception of Kinigi vis-à-vis to T58 potato cultivars. It was reported that red/purple skin-coloured potatoes produced higher (3 to 4 times) than white skin-colored while purple-fleshed potato varieties doubled white-fleshed ones in phenolic compounds (Akyol *et al*., 2016). Also, yellow-fleshed potatoes were reported to contain higher TPC and TFC than light yellow-fleshed and white-fleshed potato cultivars (Bahadori *et al*., 2023). According to Singh *et al*. (2020), red pigments i.e., anthocyanins in (red and purple skin colour) potato varieties may be the reason for that difference. Moreover, higher content of chlorogenic acid, representing 35.21-81.87% of phenolic compounds, in pigmented potatoes is another reason (Rasheed *et al.*, 2022; Bahadori *et al*., 2023). Surprisingly, even among same-coloured ten red/purple-pigmented potato cultivars, the significant difference ($P<0.01$) in TPC and TAC was observed in peel extracts (Yin *et al*., 2016). The same reason may explain the difference in this study between Kuruseke (light yellow and purple flesh) and Kinigi (light yellow flesh) cultivars.

With regard to potato maturity, the maturity period in days of potato cultivars in this study was as follows: Peco < T58 < Kirundo < Kuruseke < Kinigi. That can also support the differences found in our results of bioactive compounds. Kipkoech Kirui et al demonstrated that argument, whereby young (55 days) potato tubers produced higher levels of TGC than in matured (125 days) potato tubers (Kipkoech *et al*., 2018). In fact, the more the potato tuber is mature, the lower bioactive compounds it contains, and vice-versa; this principle might be also applicable to potato peel wastes and corresponding extracts. Apart from those characteristics, other factors such as mechanical damage and infestation (Friedman *et al*., 2018; Schieber & Saldaña, 2009) along with green-coloured tubers (Dhalsamant *et al*., 2022) can affect the content of bioactive compounds in potato tubers. However, in this study, injured, infested and green-coloured potato tubers were screened and removed at the sample preparation step.

In comparison with other findings from literature, it was observed that results of TPC were more reported than TGC, TFC and TAC. Different and many authors reported their findings on TPC from potato peels extracts, and a list of them is non-exhaustive. The ranges of TPC were 4.16 - 14.03 mg GAE /g DW (Silva-Beltran et al., 2017) and 3.2 -10.3 mg GAE/100 g DW (Amado *et al*., 2014) from peel extracts of one potato variety. Moreover, in the study on peel extracts of two and three potato varieties, TPC were 7.46 - 87.90 mg GAE/100g DW (Ben-Jeddou *et al*., 2021) and 10.1 and 40.5 mg GAE /g DW (Samotyja, 2019), respectively. In addition, in peels extracts of five and six potato varieties, TPC were 2.48 - 7.23 mg GAE/g DW (Riciputi *et al*., 2018) and 11.0-34.4 µg GAE /mg DW (Friedman *et al*., 2017), respectively; whereas peels extracts of ten pigmented potato varieties, TPC varied between 0.27 and 1.76 mg GAE/g DW (Sampaio *et al*., 2021). Furthermore, TPC of extracts of peels collected from chips factory were 1.91- 3.78 mg GAE/g DW (Helal *et al*., 2020). Peel wastes collected from household resulted in extract containing TPC of 0.19 mg GAE/g DW (Martínez-Inda *et al*., 2023).

Several authors reported flavonoids content from potato peel extracts. The range of TFC in peel extracts of non- and organic potato cultivars was 7.8 – 29.7 µg/mg DW. In that study, potato peel extracts from non-organic Red and organic Russet cultivars produced the lowest and the highest values, respectively (Friedman *et al*., 2017). Silva-Beltran *et al*. (2017) reported 1.01- 3.31 mg QE/g DW as the value range of TFC in peels extracts of Fianna potato cultivar. Potato peels from a chips processing company yielded TFC varying between 0.51 -0.96 mg QE/g DW *(Mohdaly et al*., 2013) and 0.05 – 0.13 mg Rutine/g DW (Helal *et al*., 2020), whereas potato peels from household produced 0.64 mmol QE/g DW of TFC (Martínez-Inda *et al*., 2023). The quantity of TFC in potato peels also varies with the potato skin colour, whereby coloured potato peels contained double of flavonoid compared to white potato peels (Jimenez-Champi *et al.*, 2023). Moreover, the content of individual flavonoid molecule may varies with the specific colour (white, yellow, red, pink, purple) of the potato peel (Rasheed et al., 2022).

Anthocyanin content from potato peel extracts was also reported. While TAC varied between 1.15 and 3.98 mg CGE/100g DW in CN1 potato hybrid, it was not detected in Spunta potato variety (Ben-Jeddou *et al*., 2021). TAC varied between 0.27 and 6.87 mg/100g DW in peels of Russet, Innovator, Purple and Yellow potato varieties, whereby yields of anthocyanin in peels were in order of Purple >Russet >Yellow > Innovator (Albishi *et al*., 2013). In ten pigmented (red and purple) potato cultivars, TAC ranges were from 59.67 to 293.57 mg/100 g FW (Yin *et al*., 2016). In another study on peel extracts of ten red and purple pigmented potatoes, TAC varied from 0.518 to 1.39 mg/g DW (Sampaio *et al*., 2021). In fact, TAC varies with the color of the peel, because anthocyanin compounds are responsible are responsible for the colour in peel (Jimenez-Champi *et al*., 2023). Brown *et al*. (2007) reported that purple and red peels contained higher level of anthocyanin due to the presence of high monomeric molecules of anthocyanin in pigmented potatoes. Those arguments supported results from this study: red/purple skin-coloured potato cultivars (Kuruseke, Kinigi, Peco) had higher TAC than white skin-coloured ones (T58 and Kirundo).

Glycoalkaloids are secondary metabolites with toxic properties to prevent potatoes from infections different microorganisms (bacteria, fungi, viruses) and insects (Jimenez-Champi *et al*., 2023; Pacifico *et al*., 2021). They are mainly composed of α- solanine and α-chaconine (Alves-Filho *et al*., 2018; J. Singh & Kaur, 2009). Reports from literature showed that TGC were 6.71, 71.17 and 374.62 µg/g FW in peels of Shepody, Atlantic and Russet Burbank potato varieties, respectively (Jin *et al*., 2018). In peels of eight potato cultivars, glycoalkaloids varied between 0.83 and 352.6 mg/100 DW (Friedman *et al*., 2003). Studies by Friedman et al. resulted in the TGC range of 639 -3580 µg/g DW in peels of six (3 organic and 3 non-organic) potato cultivars with higher TGC values in organic potatoes, while in their other study TGC varied between 1.2 and 5.3 mg/g DW of potato peel (Friedman et al., 2017, 2018). The TGC in potato peels ranged from 50.57 to 764.02 µg/g DW(Hossain *et al*., 2015). TGC varies with the potato cultivar as it was observed in this study. However, another factor, which was not explored in this study, is the highest levels of TGC on potato places with intense metabolic activity (skin and adjacent tissues:1.5 mm thick, potato eyes, and injured areas) (Rytel *et al*., 2013).

Effect of Extraction Method on the Composition of Bioactive Compounds

Results

Figure 1 shows results of bioactive compounds from peel extracts by the decoction (DT) and indirect ultrasound assisted extraction (DuAE) methods. Results were grouped by type of bioactive compounds. The DT method produced 4.74 mg SE/100 g for TGC, 50.39 mg GAE/100 g for TPC, 60.12 mg QE/100 g for TFC and 0.71 mg CGE/100 g for TAC. The DuAE method produced 8.52 mg SE/100 g for TGC, 873.26 mg GAE/100 g for TPC, 1170.01 mg QE/100 g for TFC and 8.73 mg CGE/100 g for TAC. In this study, the extraction method affected significantly ($P<0.0001$) the concentration yield in all studied bioactive compounds, whereby the DuAE method produced higher amount of bioactive compounds than the DT method.

Results values are grand mean (n=5) determined on dry weight basis of samples. Super scripts (a, b) on histogram indicate the difference ($P\leq 0.05$). In each category of bioactive compound, values with different superscripts letters are significant different. DT: Decoction extraction method, DuAE: Indirect ultrasound assisted extraction method.

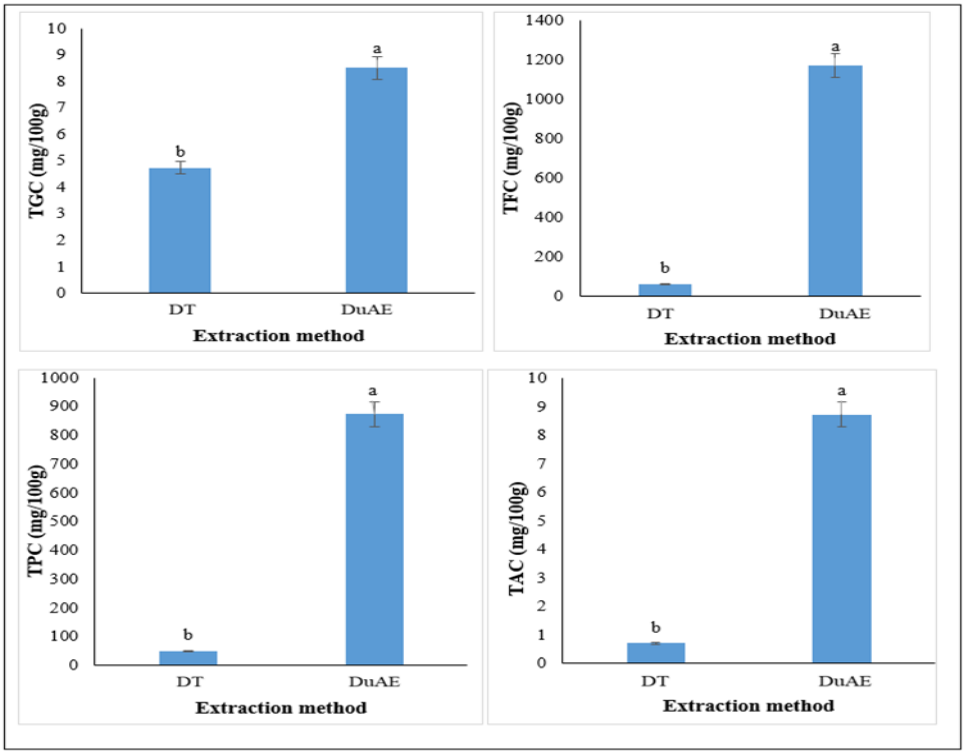

Figure 1: Effect of the Extraction Method on the Content of Bioactive Compounds

Discussion

In general, conventional extraction methods, such DT and others are prominent and commonly used to extract plant bioactive compounds (Jimenez-Champi *et al*., 2023). However, their productivity of bioactive compounds is lower than novel extraction methods. Moreover, the conventional methods were reported to exhibit disadvantages (Venturi *et al*., 2019), whereas novel methods are advantageous and more efficient (Calcio Gaudino *et al*., 2020). In fact, the efficiency of the DuAE relies on the dispersion of pressure waves, leading to cavitation, leading to the

formation of bubbles and high temperatures that disrupt cell walls, resulting in the release of cell contents into the extraction solvent (Ebringerová & Hromádková, 2010).

Results from this study are comparable with findings from literature. With regard to conventional methods, potato peel extracts by solid-liquid batch extraction resulted in 6.74 mg GAE/g DW for TPC in peel extracts (Alvarez *et al*., 2014); a conventional shaking extraction (CSE) yielded 6.26 mg GAE/g DW for TPC (Wang *et al*., 2020). In another study, TPC results by heating extraction (40°C) and maceration extraction (shaking at room temperature for 48 hours) methods of freeze-dried fresh potato peels in methanol /water (4:1 v/v) solvent were 3.83 and 2.99 Chlorogenic acid mg/g FW, respectively (Joly *et al*., 2021).

Comparing results of the DuAE from this study with other similar studies, our results were lower. That might be due to extraction conditions, which were ethanol (55% v/v), 154 W, 40 kHz, 35 min and 35°C. in this study. However, the indirect ultrasound assisted extraction (DuAE), in conditions of methanol 50%, 40 kHz, 500W, 25°C and 30min, produced 9.09 mg GAE/g DW for TPC (Wang *et al*., 2020). Moreover, the direct ultrasound assisted extraction (DUAE), in conditions of methanol 50%, 22.95 kHz, 120 W, 600mVpp of amplitude at 60° C, produced TPC of 9.33mg GAE/g. The study demonstrated that the DUAE was more efficient than the DuAE.

In addition, our results by the DuAE are also comparable with other several reports on novel extraction methods. Pressurized liquid extraction (PLE) method recovered TPC of 20.21 mg GAE/ g DW (Alvarez *et al*., 2014). Anthocyanin in potato peel by supercritical fluid extraction (SFE) and Pressurized liquid extraction (PLE) methods were 900 and 1000 mg /g, respectively (Cardoso *et al*., 2013); TGC reached the amount of 761.02 µg/g DW of potato peels by PLE (Hossain *et al*., 2015). In fact, high yields of bioactive compounds by PLE and SFE methods are due to applications of high pressure and CO_2 with a co-solvent, respectively in the extraction system (Jimenez-Champi *et al*., 2023); but the CO_2 has a limited extraction efficiency due to it low polarity to many organic molecules present in agricultural wastes(Martinez-Fernandez *et al*., 2021). Moreover, a high-pressure homogenization process together with sample alkaline pretreatment was reported to improve the extraction yield of TPC and TFC in potato peels (Zhu *et al*., 2016). Furthermore, it is worth noting that the combination of methods is more productive of bioactive compounds than a single method (Frontuto *et al*., 2019).

Interaction Effect of Potato Cultivar and Extraction Method on Bioactive Compounds

Results

The extraction process of bioactive compounds is a complicated system, which involves the interaction effect of both sample material and extraction method. The Table 3 shows results of the interaction effect of studied potato cultivars and extraction methods. The interaction effects of both potato cultivar and extraction method were significantly ($P \leq 0.05$) different on concentration yields of TGC, TPC, TFC and TAC, with exception of slight interaction effect in TGC for peels extract of Peco and Kuruseke potato cultivars. Coupling potato cultivar and extraction method factors, showed that peel extracts from Kuruseke and Kirundo cultivar produced the highest and lowest yields of phenolic compounds, respectively, for both DuAE DT extraction methods.

Table 3: Interaction Effect of Potato Cultivar and Extraction Method on Bioactive Compounds

Potato variety	Extraction method	TGC (mg SE/100g)	TPC (mg GAE/100 g	TFC (mg QE/100 g)	TAC (mg CGE/100g)
T58	DT	6.18±0.01^{d}	47.57±0.02^{h}	44.96±0.07^{h}	0.63±0.00^{g}
T58	DuAE	3.86±0.01^{g}	1199.8±0.09^{c}	822.26±0.10^{d}	8.62±0.01^{d}
Kinigi	DT	5.89±0.00^{e}	53.52±0.19^{g}	55.22±0.25^{g}	0.65±0.00^{g}
Kinigi	DuAE	17.77±0.02^{a}	1089.00±0.13^{d}	844.53±0.10^{c}	9.76±0.01^{b}
Kuruseke	DT	0.70±0.01^{j}	112.92±0.07^{f}	60.36±0.03^{f}	1.03±0.00^{f}
Kuruseke	DuAE	1.24±0.02^{i}	1599.94±0.08^{a}	1110.8±0.11^{a}	10.45±0.01^{a}
Peco	DT	4.49±0.01^{f}	56.28±0.07^{g}	58.92±0.06^{fg}	0.66±0.00^{g}
Peco	DuAE	3.70±0.01^{h}	1272.3±3.37^{b}	905.03±1.69^{b}	8.87±0.00^{c}
Kirundo	DT	6.45±0.00^{c}	32.89±0.03^{i}	29.9±0.05^{i}	0.61±0.00^{g}
Kirundo	DuAE	16.04±0.02^{b}	689.02±0.11^{e}	683.7±1.88^{e}	5.96±0.03^{e}

Results values are mean ± SD (n=3) determined on dry weight basis (DW) of samples. Super scripts (a, b, c, d, and e) on values indicate the difference ($P \leq 0.05$) of obtained results. In each column, values with the same superscript letter are not different, whereas values with different superscripts letters are different.

Discussion

Results of this study for both the DT and DuAE were still lower than other results from literture. The difference might be due to extraction conditions along with extraction solvents used. Moreover, due to filtration capacity in this study, there was no a second time extraction of sample residues during each extraction batch. In addition, other several factors (extraction temperature and time, type of solvent and solvent concentration, electrical power, etc.), which can explain the difference between results from this study and others findings, but were discussed further.

Apart from potato cultivar and extraction method as main factors, the extraction of bioactive compounds is a complicated system, which inclusively involves other different factors. The kind of solvent used, ratio of material to solvent, particle size, extraction duration and temperature were reported to affect the extraction yield of bioactive compounds (Rodríguez-Martínez *et al*., 2021). For example, an increase of temperature resulted in increased glycoalkaloids content, whereas extending extraction time did not significantly ($p \leq 0.05$) affect the yield of TGC for both solid-liquid extraction (SLE) and ultrasound assisted extraction (UAE) (Apel *et al*., 2020). The same authors reported that high temperature (85°C) in UAE system may, however, disturb the sonication effect on molecules that leads to lowering yields of bioactive compounds than in SLE system (Apel *et al*., 2020). Moreover, on each extraction method, sample treatment procedure of and process conditions such as shaking, sonication, pressure, electrical heat and waves, etc. are important factors for the extraction yield and composition of bioactive compounds (Albishi *et al*., 2013; Alvarez *et al*., 2014; Jimenez-Champi *et al*., 2023; Martinez-Fernandez *et al*., 2021; Wang *et al*., 2020; Zhu *et al*., 2016).

With regard to extraction solvents, the composition of phenolic compounds varied with the extraction solvent used (Helal *et al*., 2020). This study used deionized water for the decoction method (DT) and ethanol/water mixture for the DuAE method. Some solvents behave more efficient than others in terms of extraction yield of bioactive compounds (Amado *et al*., 2014;

Hossain *et a*l., 2015; Singh *et al*., 2020). Moreover, the effectiveness of a solvent is influenced by its concentration, temperature and processing time (Amado *et al*., 2014). Generally, methanol solvent was reported to yield higher amount of bioactive compounds regardless the extraction method on same peel sample (Helal *et al*., 2020; Hossain *et al*., 2015; Mohdaly *et al*., 2013; Rowayshed *et al*., 2015; Singh & Saldaña, 2011). The problem with methanol solvent is its toxicity and producing a mixture of phenolic acids and toxic glycoalkaloids, preventing this solvent from being used in food (Amado *et al*., 2014). Water solvent is a good one, and it performs well than other solvents in terms of extraction yield, but it yields extract with lower concentration of bioactive compounds (Kaneria *et al*., 2012; Samotyja, 2019) as it was demonstrated by Kaneria et al (2012) in the study on medicinal plants. The main reason is the limited solubility of water for the majority of phenolics from potato peels (Singh *et al*., 2020).

Furthermore, the optimization of extraction method and conditions is a key for the effective extraction of bioactive compounds. For example, a simple solid-liquid extraction in water bath system, the extraction yield was optimized at 89.9 °C in 34 min when ethanol solvents were 71.2% and 38.6% for total phenolics and flavonoids, respectively (Amado *et al*., 2014). In this study, the DuAE extraction was done in conditions used by Riciputi *et al*. (2018), who demonstrated that the optimum extraction conditions by ultra-sound assisted method were ethanol (55%), 35 °C and 1/10 sample-solvent ratio. Another example, the extraction of polyphenols at high heating temperature and time from potato peels with high sugar/starch content can result in extract containing sugars, which interfere with Folin- Ciocalteu reagent during determination of phenolics content, then lead to the overestimation of TPC (de Andrade Lima *et al*., 2021; Joly *et al*., 2021).

Ending this discussion, it is worthy to note that, in this study, results of the extraction yields and composition of bioactive compounds from peel extracts were higher or lower than reported from literature. That difference could be supported by several reasons. First, samples of potato varieties used to obtain peel waste extracts were different in terms of phenotypic and genotypic characteristics, growing conditions and season, and even geographic location. Second, extraction methods were different in extractions conditions, such as time, heating temperature, treatment waves and power intensity, solvent type and concentration. Despite those limitations, DT and DuAE extraction methods produced, however, reasonable results of the composition of bioactive compounds. Moreover, the use of DT and DuAE methods was advantageous due to their feasibility, practicability, cost-effectiveness and safety of solvents (Singh *et al*., 2020; Ampofo & Ngadi, 2022; Jimenez-Champi *et al*., 2023). In addition, the use of water and ethanol as extrcation solvents was an environment-friendly choice to avoid hazardous organic solvents (Jimenez-Champi *et al*., 2023; B. Singh *et al*., 2020).

In overall, the DuAE method was more effective than the DT method to yield extract with higher amount of phenolic compounds (TPC, TFC, TAC), except on the content of Glycoalkaloids (TGC), which varied depending on the potato cultivar for the two extraction methods. However, regardless the potato cultivar and extraction method, TGC amount did not exceed the safe limit (< 20 mg/100g) for food industry applications.

4.0 CONCLUSION AND RECOMMENDATIONS

This study demonstrated that the difference in the extraction effectiveness of bioactive compounds from potato peel extracts was due to both potato cultivar and extraction method direct effect. Peel waste extracts from skin and flesh-coloured potato cultivars resulted in higher amount of phenolic

compounds than peel extracts from white skin and yellow flesh potato cultivars. The DuAE novel extraction method also performed better in higher amount of phenolic compounds than the DT conventional method. In this study, the package of extraction process and conditions used for both DT and DuAE method allowed getting potato peel extracts with acceptable results of bioactive compounds, useful substances for industrial applications. However, improving and optimizing processes of extraction methods used in this study are recommended for further investigation. Results from this study were limited to set extraction conditions and parameters such as temperature and time, substrate weight, solvent type and volume, vacuum filtration capacity, etc. Therefore, the variation of those conditions and parameters could be explored for the best effective extraction of bioactive compounds from potato peels wastes.

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Conflicts of Interest

The authors declare no conflicts of interest.

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