Relationships between environmental factors and the quality of berries grown in the Fort McMurray region, Alberta

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ABSTRACT

Fort McMurray has experienced significant environmental disruptions, raising concerns about chemical releases that affect the environment, particularly berries. This thesis explores the relationship between environmental factors and the nutritional quality of pin cherry (*Prunus pensylvanica L.F.*) and common blueberry (*Vaccinium myrtilloides Michx*) fruits and soil in Fort McMurray (reclaimed and natural lands). Samples were collected in August 2022 and analyzed for chemicals and quality variables.

The results revealed concentration variations among samples, with hydrocarbons higher in reclaimed areas and blueberries than others and soil surpassing those in fruits. Copper and iron in fruits exceeded regulatory limits. A strong association between soil chemicals and alkylated hydrocarbons in fruits explained most differences. Soil trace elements and properties were primary environmental drivers, while hydrocarbons were secondary influencers, evident mainly in reclaimed berry environments. Antioxidant-focused nutritional quality in reclaimed berries was predominantly influenced by these key drivers in soil, requiring consistent monitoring.

RÉSUMÉ

Fort McMurray a connu d'importantes perturbations environnementales, soulevant des inquiétudes quant aux rejets de produits chimiques qui affectent l'environnement, en particulier les baies. Cette thèse explore la relation entre les facteurs environnementaux et la qualité nutritionnelle des fruits et du sol du cerisier à grappes (*Prunus pensylvanica L.F.*) et du bleuet commun (*Vaccinium myrtilloides Michx*) à Fort McMurray (terres réhabilitées et naturelles). Des échantillons ont été prélevés en août 2022 et analysés pour les produits chimiques et les variables de qualité.

Les résultats ont révélé des variations de concentration entre les échantillons, les hydrocarbures étant plus élevés dans les zones remises en état et les myrtilles que dans les autres, et le sol dépassant les fruits. Le cuivre et le fer présents dans les fruits dépassaient les limites réglementaires. Une forte association entre les produits chimiques du sol et les hydrocarbures alkylés dans les fruits explique la plupart des différences. Les oligo-éléments et les propriétés du sol ont été les principaux facteurs environnementaux, tandis que les hydrocarbures ont exercé une influence secondaire, qui s'est manifestée principalement dans les environnements de baies récupérées. La qualité nutritionnelle des baies récupérées, axée sur les antioxydants, a été principalement influencée par ces facteurs-clés dans le sol, ce qui nécessite une surveillance constante.

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ABBREVIATIONS

APAHs alkylated polycyclic aromatic hydrocarbons
As arsenic
B boron
Cd cadmium
CEC cation exchange capacity
Co cobalt
Cr chromium
Cu copper
EC electrical conductivity
Fe iron
Hg mercury
Mg magnesium
Mo molybdenum
Ni nickel
OM organic matter
OS Oil Sands
PAHs polycyclic aromatic hydrocarbons
Pb lead
PCA Principal Component Analysis
PCR Principal Component Regression
ROS Reactive Oxygen Species
RS Natural Site
Se selenium
SS1 Reclaimed Site 1
SS2 Reclaimed Site 2
SS3 Reclaimed Site 3
TAA Total Antioxidant Activity
TAC Total Antioxidant Capacity
TAnC Total Anthocyanin Content
TEs trace elements
Total K potassium
Total N nitrogen
Total P phosphorus
TPC total phenolic content
Zn zinc

CHAPTER 1. INTRODUCTION

A. Northern Alberta

The boreal forest is the largest ecosystem in Canada, covering 58% of Alberta's land base (Campos-Ruiz *et al.,* 2018). It consists of a mix of forest types with tree species (Conifers such as jackpine and deciduous such as trembling aspen) interspersed with wetlands and rivers (Shaw *et al.,* 2021). Fort McMurray is in the central mixed wood subregion, characterized by upland and wetland ecosystems (Shaw *et al.,* 2021). Anthropogenic disturbances, such as oil and gas development in the energy sector, along with natural disturbances like wildfires, have significantly impacted this region for a prolonged period (from late 1960s to the present) (Shaw *et al.,* 2021). These disturbances raise concerns about their impact on vegetation, particularly from indigenous communities who rely on the boreal forests for traditional and spiritual purposes (Kusnetz *et al.,* 2021; Shaw *et al.,* 2021; Montesanti *et al.,* 2021).

Restoring the health of the boreal forest ecosystem (*i.e.,* reclamation activities) is a priority for various stakeholders, including academia, industry, indigenous communities, and government sectors (Shaw *et al.,* 2021; Powter *et al.,* 2015). To assist in restoration strategies, the scientific research community has been conducting analyses, including exploratory and predictive approaches (An *et al.,* 2019; Das Gupta and Pinno *et al.,* 2020). Both analyses play crucial roles in research (An *et al.,* 2019; Das Gupta and Pinno *et al.,* 2020). Predictive analyses allow researchers to forecast the outcomes of restoration efforts and improve restoration strategies (An *et al.,* 2019; Das Gupta and Pinno *et al.,* 2020). On the other hand, exploratory analyses are highly important and are conducted for understanding and identifying key factors influencing vegetation, providing valuable insights into the complex dynamics of vegetation in the boreal forest of

Northern Alberta (Geographic Dynamics Corporation, 2010; What makes a wetland, 2018; Das Gupta and Pinno *et al.,* 2020; An *et al.,* 2019).

B. Emission Sources in Alberta

Due to significant sources of disturbances, such as wildfires and industrial activities, along with other external factors like vehicles and agricultural practices, various activities (natural or anthropogenic) in Alberta can lead to the generation of dust, smoke, and emissions (Brown, 2019). These activities release chemicals into the environment, contributing to regional changes (Brown, 2019). Air pollutants, including nitrogen oxides, sulfur dioxide, volatile organic compounds, particulate matter with a diameter <2.5 μm, and toxic compounds such as polycyclic aromatic compounds (PACs) and heavy metals (HMs), are some of the common contaminants detected in various environmental compartments (*e.g.,* soil, plants) in Alberta (Brook *et al.,* 2019; Weinhold, 2011).

Kohl *et al.* (2018) found trace elements (TEs), such as arsenic, molybdenum, chromium, copper, and nickel, in urban ashes from the 2016 wildfire (Horse River) in Fort McMurray that exceeded their regulatory guidelines. They also observed higher concentrations of Polycyclic Aromatic Hydrocarbons (PAHs), belonging to the PAC group, in the urban and forest wildfire ashes compared to house dust (Kohl *et al.,* 2018). Zhang *et al.* (2016) found that dust from petroleum coke derived from bitumen (an upgrading by-product of oil sands mining) was a significant source of PAHs in the Athabasca OSR. They found higher concentrations of PAHs on average in moss (*Sphagnum fuscum*) near the OS activity compared to moss from distant areas, a temporal increase in PAHs in peat collected near the activities, and that petroleum coke was the main source of PAHs

in moss (Zhang *et al.,* 2016). Additionally, they found that petroleum coke is a significant source of elements, such as nickel and molybdenum, in the OSR (Zhang *et al.,* 2016). These findings highlight that both natural and anthropogenic activities contribute to releasing chemicals of concern (like trace elements and PAHs) in Alberta, particularly in the Athabasca OSR (Zhang *et al.,* 2016). However, the Canada Energy Regulator indicated that, as of 2020, oil and gas production in Alberta remains the largest sector of greenhouse gas emissions at 52% (followed by electricity and transportation at 11%) (Canada Energy Regulator, 2022). Therefore, oil sands activities are often the focus of interest when assessing the environmental impacts, particularly the effects of these chemicals of concern (Canada Energy Regulator, 2022).

C. Concerns on Alberta's Environmental Health

There have been growing concerns about Alberta's environmental health, especially regarding the increasing frequency of wildfires and the continuous activities of the OS industry. Reports, such as the one discussed by Snowdon (2023), have highlighted the rising experience of smoke-filled summers in Alberta due to more frequent and prolonged wildfires. Air quality health index ratings suggest significant health risks potentially arising from the persistent pollutants released from wildfire smoke (Snowdon, 2023). Recent news articles have voiced concerns raised by indigenous communities and environmental groups in Alberta regarding potential health implications from OS activities and the environmental impacts of waste, such as tailings ponds, being released into surrounding rivers, National Parks, and traditional lands (Weber, 2022; Desmarais, 2020). These articles have also stressed the need to expand budgets for environmental monitoring (Weber, 2022; Desmarais, 2020). Zhang *et al.* (2022) conducted a study comparing PAHs (polycyclic aromatic hydrocarbons) and element concentrations in living moss (*Sphagnum fuscum*) sampled from different sites (bogs) after the 2016 wildfire in Fort McMurray and the AOSR with data from the

same sites before and after the wildfire, as well as remote sites from Alberta and Ontario. The study found that certain PAHs, such as naphthalene and fluorene, increased significantly after the wildfire. Still, most elements in the AOSR sites did not show a post-wildfire increase (except for one burned site, but they identified that the elevated nickel, selenium, and molybdenum are of bitumen origin) (Zhang *et al., 2022*).

Moreover, most PAHs and elements did not significantly correlate with retene, an alkyl substituted PAH and a marker of wildfire, indicating that they do not share a common source (Zhang *et al., 2022*). These findings suggest that even after the major 2016 wildfire, OS activities remained the dominant source of these chemicals in the affected sites (Zhang *et al., 2022*). The study also developed a model that indicated haul road dust, overburden, oil sands ore, upgrader stacks, and hauler emissions as major sources of elements in the AOSR during 2013-2014 (Zhang *et al., 2022*). In particular, the Fort McKay community in the AOSR was found to have OS and haul road dust being the major sources of particulate matter in their area (Zhang *et al., 2022*). This community has also reported experiencing a reduction in areas with high traditional plant potential since the development of OS in the 1960s and significant losses in traditional berry sites since 2007 (Fort McKay, 2010). Furthermore, a study by Natcher *et al.* (2020) conducted a consensus analysis with Indigenous residents living in Alberta's OSR, revealing that 87% of the respondents believe that the Peace and Athabasca Rivers are contaminated due to OS activities, based on their shared cultural knowledge in the region. As a result, OS activities are of particular focus and interest when assessing the environmental health in Alberta, particularly regarding the effects of these chemicals.

D. An Overview of the Oil Sands (OS)

OS are found in Western Canada, primarily in Northern Alberta, and contain 10% of the world's oil reserves (Duhatschek, 2022). They consist of bitumen surrounded by sand, clay, and water.

AOSR has the largest deposit, and daily production is 3.6 million barrels/day, contributing to Canada's economic growth (Duhatschek, 2022).

OS bitumen is extracted via surface mining or in-situ methods (Canada, Natural Resources, 2016). Surface mining is used when the reserves are closer to the surface, but only 20% of reserves can be recovered this way (OS Discovery Centre, n.d.). The remaining 80% are too deep for surface mining and must be extracted through in-situ techniques (OS Discovery Centre, n.d.).

OS extraction has been a controversial issue due to its potential release of chemicals of concern (COC) into the environment (Kelly *et al.,* 2009 and 2010). To investigate this, Kelly *et al.* (2009) conducted a four-month-long study. They estimated the release of 11,400 tons of airborne particulates, including 391 kg of polycyclic aromatic compounds (PACs), within a 50 km radius of the Athabasca OS mining facilities. This suggested OS development as a source of PACs deposition on the Athabasca River. Kelly *et al.* (2010) also found HMs, including cadmium, lead, and mercury, in the Athabasca River and its tributaries that exceeded Canadian Water Quality Guideline levels. However, the study faced criticism for its limitations and analysis of data (Kelly *et al.,* 2009 and 2010).

Following studies, such as Kurek *et al.* (2013) and Thienpont *et al.* (2017), have demonstrated an enhancement in PACs in sediments since the development of OS mining, with PAC concentrations 2.5-23 times higher in recent sediments compared to pre-mining concentrations. Bari *et al.* (2014) discovered enhanced atmospheric deposition of pollutants, including metals and PAHs, in sites within 20 km of the Athabasca OS compared to distant sites. Kirk *et al.* (2014) also found increased

atmospheric deposition of mercury and methylmercury in springtime snowpacks closer to the Athabasca OS region. These studies contribute evidence of potential COC released from OS mining activities.

Due to these environmental disturbances, the Government of Alberta requires the OS industry to fully reclaim the disturbed land after bitumen extraction to ensure its productivity and ability to sustain vegetation and wildlife (Government of Alberta, 2015). Historically, the focus was on reclaiming overburdened waste, but now OS mining operations require the reclamation of waste released from bitumen mining extraction (BGC Engineering Inc, 2010). There is growing interest in reclaiming tailings waste due to potential leakages from tailings ponds (BGC Engineering Inc, 2010). Reclaimed landscapes can be divided into two categories (dry and wet), where dry landscapes are focused upon here as they represent the selected reclaimed sites in this study (Macyk *et al.,* 1998; Wellstead *et al.,* 2016). The reclamation process to generate a dry landscape is shown in Figure 1, which was designed based on the information from Wellstead *et al.* (2016).

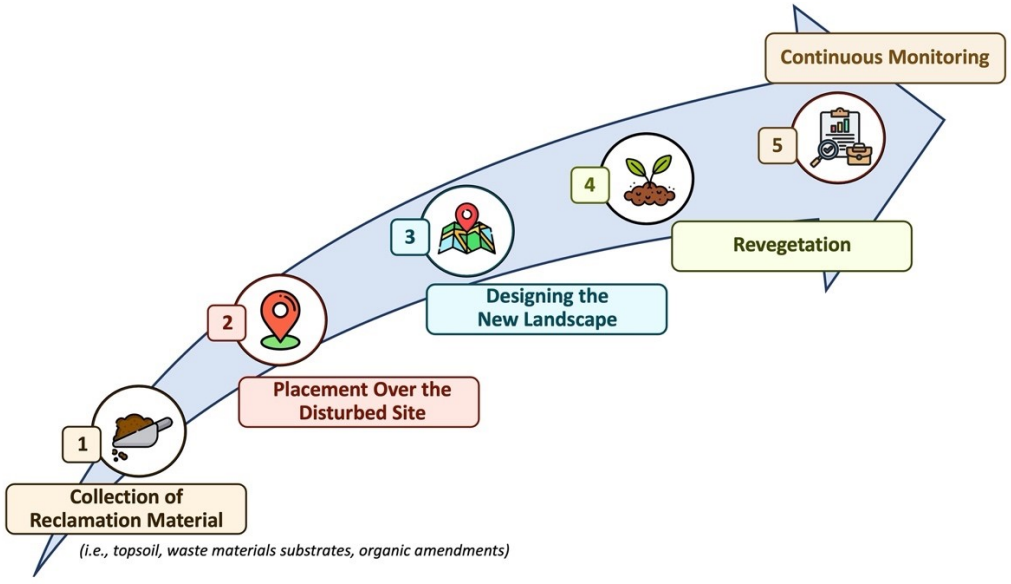


Figure 1: The reclamation process to generate a dry landscape (created by Chathumi De Silva)

To reclaim these landscapes, OS operations typically use organic soil materials (*e.g.,* peat and peat-mineral mixes), which are often components of either the topsoil or substrates to improve plant growth (Alberta environment and water, 2011). Other reclamation organic soil materials, which include upland surface soils, which are typically lower in organic content and higher in minerals, compared to peat are also used to enhance plant species diversity, richness, abundance, and soil nutrient availability (Alberta environment and water, 2011). Most sites use a combination of organic and mineral soil (*e.g.,* peat mixed with mineral soil) and layers to form a soil-cover design (Alberta environment and water, 2011). The soil cover typically consists of a cover soil and subsoil layer, with organic materials in the cover soil and reconstructed subsoil containing mineral materials (Alberta environment and water, 2011). The depth of the subsoil is based on the substrate (primarily overburden and treated tailings) reclaimed to prevent water and plant penetration to toxic materials beneath (Alberta environment and water, 2011).

E. External activities impacting soil quality

Overall, the sections above shed light on various activities specific to Alberta that can significantly impact their surrounding environment. Among these activities, wildfires, bitumen extraction, toxic OS waste, and reclamation play crucial roles in releasing chemicals and affecting the environment, with soil being particularly susceptible to their effects, which are highlighted here. For instance, Campos *et al.* (2016) revealed significantly higher concentrations of elements like cadmium and lead in burnt soil samples compared to unburnt soil after (immediately and 4-15 months after) a wildfire in northcentral Portugal. Similarly, Boutin and Carpenter (2017) conducted a study in Fort McMurray, where they found higher concentrations of total metals and PAHs, including alkylated PAHs, in soil samples near the OS activity area compared to sites located farther away. The correlation between the distance from upgrader facilities, where the bitumen is processed into

products like synthetic crude oil and the concentration of certain elements such as chromium, cobalt, copper, iron, lead, molybdenum, and nickel showed that the highest concentrations were present in the soil of sites closest to the upgrader (Boutin and Carpenter, 2017). In fact, these metals and total PAHs exceeded safety guideline limits for soil in all studied sites, suggesting that the detected chemicals can travel long distances, leaving traces of contamination in distant locations and eventually depositing onto their soil (Boutin and Carpenter, 2017). The results also support previous findings that these metals can travel through the atmosphere, reaching distances surpassing 50 to 90 km from OS upgraders (Boutin and Carpenter, 2017).

Meanwhile, PAHs, naturally occurring in bituminous fossil fuels, can be transported through airborne emissions (Allen, 2008; Kelly *et al., 2010*; Olson, 2004). Furthermore, Korosi *et al.* (2013, 2016) identified elevated concentrations of alkylated PAHs in soil samples collected near OS in-situ drilling areas and Hilda Lake, located near the Alberta OS in-situ installations. Additionally, Zhu *et al.* (2017) made discoveries about using unsuitable reclamation materials, particularly in areas with high metal content, resulting in enhanced concentrations of metals in the reclaimed soil. Moreover, Yan *et al.* (2017) demonstrated how the use of certain reclamation materials could impact potential toxic chemical concentrations in soil layers. Furthermore, Mackenzie (2006 and 2012) highlighted the typical lack of organic matter and nutrients in OS mine wastes, leading to low water retention and ultimately affecting the chemical properties of the soil, hindering plant growth. Overall, these findings underscore the importance of considering soil quality as a focal point when assessing environmental health, given that these chemicals are present and can accumulate in the soil, thereby impacting the overall soil quality in Alberta's environment (Opeyemi *et al.,* 2020).

F. Assessing Soil Quality

Physicochemical Properties

Assessing the concentration of soil properties is essential in determining soil health and overall quality (Opeyemi *et al.,* 2020; Woldeyohannis *et al.,* 2022; Oliver *et al.,* 2013). These properties fall into two main categories: physical and chemical properties, collectively known as physicochemical properties (Opeyemi *et al.,* 2020; Woldeyohannis *et al.,* 2022; Oliver *et al.,* 2013). Chemical indicators, such as soil pH, organic matter (OM), total nitrogen, available phosphorus, exchangeable cations (*e.g.,* potassium), and electrical conductivity (EC), focus on soil nutrient content (Opeyemi *et al.,* 2020; Woldeyohannis *et al.,* 2022; Oliver *et al.,* 2013). Conversely, physical indicators, such as soil texture and moisture, relate to soil structure (Opeyemi *et al.,* 2020; Woldeyohannis *et al.,* 2022; Oliver *et al.,* 2013).

1. pH

Soil pH, a measure of acidity or alkalinity, is determined by the concentration of hydrogen ions (H^+) and directly influences nutrient availability, making it crucial for soil health (Msimbira and Smith, 2020). Agegnehu *et al.* (2021) found that soil acidity (pH < 7) can decrease nutrient availability, particularly for essential nutrients like phosphorus, which become less accessible due to enhanced sorption and conversion into less available forms. Conversely, nitrogen availability follows an opposite pattern, decreasing as pH increases due to a process called mineralization (Agegnehu *et al.,* 2021). However, decreasing pH can increase nitrogen availability through higher ammonium ion uptake by plants (Barrow and Hartemink, 2023; Agegnehu *et al.,* 2021). In the case of potassium, its uptake is slowed down as soil pH increases, owing to the rising negative charge on soil particles, which reduces cation movement (Barrow and Hartemink, 2023; Agegnehu *et al.,* 2021). Nonetheless, potassium uptake involves exporting protons, making it favored by plants at higher soil pH concentrations (Barrow and Hartemink, 2023; Agegnehu *et al.,* 2021). Furthermore,

Liu *et al.* (2013) observed a negative correlation between soil pH and total nitrogen, and total phosphorus, indicating close relationships and co-variation.

2. Organic Matter (OM)

Soil Organic Matter (SOM) plays a critical role in enhancing nutrients (elements absorbed by plants primarily from the soil, essential for physiological processes in plants) availability and uptake, while also exerting a strong influence on nutrient storage and accessibility in soils (Gerke, 2022). It serves as the primary reservoir for essential macronutrients (elements required in large amounts for optimum plant growth and development) like nitrogen and phosphorus, and it also regulates the availability of essential micronutrients (elements required in smaller quantities than macronutrients) to plants (Gerke, 2022). Khadka (2016) reported a strong positive correlation between SOM and primary macronutrients (required in large amounts), including nitrogen, phosphorus, and potassium. Conversely, a significant negative correlation was observed with secondary macronutrients (plants require them in smaller quantities than primary macronutrients) such as calcium and magnesium (Khadka, 2016; Grzebisz *et al.,* 2022). These findings indicate that SOM governs the availability of macronutrients, with higher SOM content enhancing the availability of primary macronutrients and vice versa for secondary macronutrients (Khadka, 2016). Consequently, SOM is crucial in maintaining a balanced macronutrient concentration in the soil (Khadka, 2016).

3. Primary Macronutrients

Primary macronutrients—nitrogen, phosphorus, and potassium—are essential for various plant processes, including root growth (Lhamo and Luan, 2021). Lhamo and Luan (2021) demonstrated

their significance by observing shunted shoot growth and altered root form in *Arabidopsis thaliana* seedlings when deficient in nitrogen, phosphorus, or potassium supply. Additionally, Zama *et al.* (2022) conducted a greenhouse study with *Vachellia sieberiana*, revealing that nitrogen-enriched soil exhibited higher acidity compared to phosphorus-enriched soil. The excessive soil acidification in the nitrogen-rich soil resulted in phosphorus becoming unavailable, leading to reduced sapling growth of *Vachellia sieberiana* (Zama *et al.,* 2022). These findings underscore the role of soil properties, such as pH, in influencing the availability of essential macronutrients and highlight the importance of macronutrient interactions in the soil to optimize plant growth and development (Zama *et al.,* 2022).

4. Cation Exchange Capacity (CEC)

CEC is a crucial measurement of a soil's capacity to retain and exchange positively charged ions, such as potassium (K) (Solly *et al.,* 2020; Cornwell, 2014; Olorunfemi *et al.,* 2016). Soils with higher CEC values have more negatively charged binding sites, enabling them to hold more exchangeable cations, including potassium (Solly *et al.,* 2020; Cornwell, 2014; Olorunfemi *et al.,* 2016). Conversely, soils with lower CEC values have fewer negatively charged sites and thus can hold fewer cations (Solly *et al.,* 2020; Cornwell, 2014; Olorunfemi *et al.,* 2016). Liao, Xu, and Zhu (2015) demonstrated that soil properties like silt, clay, and organic matter (OM) significantly and positively correlate with CEC, mainly due to the negative charges on these properties attracting positively charged ions (cations). Furthermore, the study found a significant and positive correlation between CEC and soil pH, indicating that as the pH increases, the number of negatively charged sites also increases, leading to higher CEC (Liao, Xu, and Zhu, 2015; Oyebiyi *et al.,* 2018). This highlights the influence that other soil properties can have on CEC and emphasizes how

changes in CEC can impact the availability of nutrients for plants (Liao, Xu, and Zhu, 2015; Oyebiyi *et al.,* 2018).

5. Electrical Conductivity (EC)

EC, a measure of the soil's electrical conductivity, serves as an indicator of dissolved ions in the soil solution. Mazur *et al.* (2022) established a strong correlation between EC and soil moisture, indicating its association with soil texture. Rodríguez-Pérez *et al.* (2011) observed a significant and strong negative correlation ($r > -0.6$) between sand content and EC, while a significant and strong positive correlation ($r > 0.6$) was found between clay content and EC. Soil texture is influenced by the size of sand and clay particles, with clay particles being smaller, resulting in greater surface area and improved water retention (Rodríguez-Pérez *et al.,* 2011; O'Green, 2013). Hence, soils with higher clay and lower sand content tend to have higher moisture concentrations, leading to increased EC (Rodríguez-Pérez *et al.,* 2011; O'Green, 2013). Rusydi (2017) presented a mathematical equation illustrating the relationship between total dissolved ions and EC, demonstrating that as ion concentration in water rises, its electrical conductivity also increases. However, this direct linear relationship may not apply to all conditions (Rusydi, 2017). In general, higher moisture concentrations correspond to higher dissolved ion content, hence higher EC values (Rusydi, 2017).

6. Soil Particles

Soil comprises various particles, primarily distinguished by their size (Deng *et al.,* 2017). The smallest particles are clay (< 0.002 mm), followed by silt (0.002-0.05 mm), sand (0.05-1 mm), and the largest being gravel (1-2 mm) (Deng *et al.,* 2017). These mineral particles, particularly sand,

silt, and clay, are crucial when assessing physical properties like soil texture, which focuses on their proportions, and soil structure, which concentrates on their arrangements (Deng *et al.,* 2017). Bacq-Labreuil *et al.* (2019) demonstrated that soil texture can influence soil structure, affecting the types of plants that can thrive and develop successfully. For instance, a higher proportion of clay compared to other particles led to changes in the soil structure, such as higher and smaller aggregates, lower pore-connectivity, and higher surface density, promoting the presence of *Phacelia tanacetifolia* plants (Bacq-Labreuil *et al.,* 2019). Hence, soil particles play a pivotal role in determining the ideal soil type for supporting successful vegetation growth (Bacq-Labreuil *et al.,* 2019; Rashid *et al.,* 2021). Moreover, these soil particles can have varying effects on other physicochemical properties of the soil (Yunan *et al.,* 2018). Yunan *et al.* (2018) revealed a significant positive correlation between CEC and clay and silt in soil samples from different provinces of China. Conversely, they found a negative correlation between CEC and sand, suggesting that an increase in the size of sand particles has an inverse relationship with CEC (Yunan *et al.,* 2018; Guibert *et al.,* 1999). Liu *et al.* (2022) found a significant positive correlation between clay content and soil moisture, while a significant negative correlation existed between soil moisture and sand and silt content in samples from the Loess Plateau and the Maowusu Desert in China. This indicates a direct relationship between the composition of soil particles and soil moisture concentrations (Liu *et al.,* 2022).

Chemicals

The assessment of soil quality also involves the evaluation of various inorganic and organic chemicals, such as trace elements (TEs) and Polycyclic Aromatic Hydrocarbons (PAHs), which can occur naturally in the soil but may also be released into the environment at concentrations above the optimal range due to natural processes (*e.g.,* rock weathering, soil erosion, wildfires) or

anthropogenic activities (*e.g.,* oil sands (OS) mining) (Bao *et al.,* 2014; Centers for Disease Control and Prevention, 2022). These chemicals are of significant concern because they are persistent, non-degradable, and can accumulate in the soil, potentially impacting the health of the surrounding environment, including plants (Bao *et al.,* 2014; Centers for Disease Control and Prevention, 2022; Krzebietke *et al.,* 2018; McComb *et al.,* 2014). As a result, they are commonly assessed to evaluate soil quality (Bao *et al.,* 2014; Centers for Disease Control and Prevention, 2022; Krzebietke *et al.,* 2018; McComb *et al.,* 2014).

Therefore, another approach to assess soil quality is to determine the sources of the detected chemicals, whether natural, mixed, or anthropogenic (Shao *et al.,* 2018). Spolaor *et al.* (2021) highlighted that TEs, such as arsenic, may originate from fossil production, while TEs, like lead can be associated with smelting and oil combustion activities. Therefore, location and dominant types of activities, whether natural or anthropogenic, can help identify the sources of these chemicals (Spolaor *et al.,* 2021). For instance, studies conducted around the Athabasca OS mining facilities revealed significant environmental impacts, such as the previous studies by Kelly *et al.* (2009), Kelly *et al.* (2010), Kurek *et al.* (2013), Thienpont *et al.* (2017), Bari *et al.* (2014), Kirk *et al.* (2014) mentioned in section D. These studies suggest that the some of these TEs and PAHs released into the environment are likely sourced from OS activities, given the dominance of industrial emissions in the Athabasca region.

Wang *et al.* (2023) conducted a principal component analysis (PCA) to investigate the variance in soil TEs in the Yangtze River Delta area, China. The PCA yielded two principal components, PC1 and PC2, which together accounted for the highest variance in their dataset. PC1 was found to be strongly positively associated with changes in iron, aluminum, magnesium, potassium, and manganese (Wang *et al.,* 2023). These elements, originating from geological parent materials, were identified as the primary drivers of the overall soil composition in the studied area (Wang *et*

al., 2023). They play a significant role in shaping the variability explained by PC1, indicating their importance in determining the soil's elemental makeup (Wang *et al.,* 2023).

On the other hand, PC2 exhibited positive correlations with changes in copper, zinc, and arsenic (Wang *et al.,* 2023). Although PC2 explained a considerable amount of variance in the data, it was lower than PC1 in terms of explanatory power (Wang *et al.,* 2023). Wang *et al.* (2023) also suggested that the elements associated with PC2 were derived from anthropogenic activities, indicating human influence on the soil's elemental composition. While these anthropogenic elements also contributed to the overall composition of the soil, they were not as influential as the natural elements linked to PC1 (Wang *et al.,* 2023). The findings of Wang *et al.* (2023) highlight the importance of statistical analyses like PCA in determining the association between different chemical variables in the soil. By identifying the primary drivers of soil composition, such as the natural elements represented by PC1, researchers can better understand the sources of these elements and their potential impact on soil health and quality (Wang *et al.,* 2023). In cases where certain chemicals originate from anthropogenic sources and are associated with the principal components with the highest variance in the dataset, special attention should be given to them, as they may have more significant implications for soil management and environmental health (Wang *et al.,* 2023).

In addition to TEs, organic PAHs in soil can also impact the chemical contents in plants (Zhao *et al., 2022*; Molina and Segura, 2021). These COC, particularly heavy-weight PAHs and metals are present in atmospheric particulate matter (consists of inorganic ions) that can be directly deposited on soil (Zhao *et al., 2022*; Molina and Segura, 2021). The plant roots can absorb these chemicals, leading to their accumulation and transfer to the aerial parts of the plant (Zhao *et al., 2022*; Molina and Segura, 2021). Zhao *et al.* (2022) found significant positive correlations between PAH

monomer content (*e.g.,* acenaphthylene, anthracene, benzo[k]fluoranthene, benzo[b]fluoranthene, and dibenzo[a,h]anthracene) and the total PAHs in plants (*Zea mays L.*, *Bidens pilosa L.*, and *Gaillardia pulchella Foug*). They also observed a correlation between the PAH content in the soil from the same location (study site in different major lakes in eastern China), suggesting an influence of PAHs in the soil on the PAHs in the plants (Zhao *et al., 2022*). However, some PAHs showed poor correlations between the sampled soil and plants, possibly due to the influence of the plant species (Zhao *et al., 2022*; Sun *et al.,* 2010).

Similar to TEs, the absorption of PAHs by plants is dependent on the plant species, as well as their mobility and availability based on the soil characteristics (Wei *et al.,* 2017). For instance, SOM is a significant soil chemical property that impacts the bioavailability of PAHs in soil (Wei *et al.,* 2017). SOM can adsorb hydrophobic organic compounds, such as PAHs (Wei *et al.,* 2017). Wei *et al.* (2017) conducted pot experiments to investigate the effects of dissipation and phytoremediation of alfalfa (*Medicago sativa L.*) for PAHs. They found that soils contaminated with PAHs for > 8 years with different soil organic carbon (SOC) treatments (1.41% and 8.51%) exhibited varied results because SOC is the primary component of soil organic matter (Wei *et al.,* 2017). Soil with a higher % of SOC content showed reduced PAH degradation rates, resulting in lower phytoremediation efficiency (Wei *et al.,* 2017). This suggests that the presence of SOM, particularly in soil where PAHs are present, causes PAHs in the soil to become adsorbed, making them less bioavailable for uptake by plants (Wei *et al.,* 2017).

Ali *et al.* (2022) discussed the co-existence of PAHs and metals, as they are present in various environmental media, thereby leading to potential contamination of the environment and impacting the health of surrounding organisms, including plants. The authors indicated that the

bioavailability of these chemicals to organisms could be influenced by three primary factors: soil properties, chemical coordination, and biological factors, with a focus on soil properties in this study (Ali *et al.,* 2022). For instance, based on results from multiple studies, they highlighted that soil pH is a significant soil factor influencing the bioavailability of combined PAHs and metals (Ali *et al.,* 2022). Neutral to alkaline pH reduces the bioavailability of metals such as zinc, copper, iron, manganese, cadmium, and lead. At the same time, PAHs show increased bioavailability under slightly acidic to alkaline soil pH concentrations (Ali *et al.,* 2022). Moreover, the authors mentioned that small soil particles (*i.e.,* clay) increase the immobilization of both PAHs and arsenic in soil due to their large surface areas, facilitating the binding of these chemicals and resulting in reduced bioavailability (Ali *et al.,* 2022). SOM was also found to bind to both PAHs and metals, leading to a reduction in their bioavailability and their persistence in soil over time (Ali *et al.,* 2022). These findings underscore the importance of assessing both elements (particularly metals) and PAHs when evaluating the influence of soil on plant nutrients (Ali *et al.,* 2022). Therefore, current research should focus on studying the interactions between multiple chemicals or chemical groups rather than solely examining single variables, as such interactions are commonly found in the natural environment (Ali *et al.,* 2022). A comprehensive understanding of these co-influences will provide better insights into their impact on plants (Ali *et al.,* 2022).

G. Fruit Quality Variables

1. Chemicals

Variables determining plant quality are crucial in assessing the overall nutritional value when consuming plants, particularly fruits (Unaegbu *et al.,* 2016). Among these variables, the concentrations of TEs and organic PAHs and their derivatives are of particular importance (Unaegbu *et al.,* 2016). TEs, including magnesium, boron, iron, zinc, copper, and molybdenum,

are considered essential for optimal plant growth and development (Unaegbu *et al.,* 2016). These TEs are absorbed by plants from the soil and play a vital role in ensuring the production of high-quality fruits (Unaegbu *et al.,* 2016). On the other hand, certain TEs, like cadmium, chromium, selenium, lead, and mercury, lack essential biological significance for plant development and can even have detrimental effects when present in excessive amounts (Unaegbu *et al.,* 2016). Alzahrani *et al.* (2017) conducted a study measuring the concentrations of different essential TEs and non-essential metals in common fruits and vegetables (*Caralluma munbayana*, *Caralluma hesperidum*, *Vigna unguiculata*, *Ficus carica*, *Annonaceae* seeds, *Annonaceae* fruits, *Foeniculum vulgare*, and *Nigella sativa*) from Saudi Arabia. The research revealed that certain pairs of essential TEs (*i.e.,* magnesium-calcium) were significantly and strongly positively correlated, indicating that these analyzed foods serve as a source of a variety of nutrients (Alzahrani *et al.,* 2017). On the other hand, the non-essential/toxic pairs of elements (*i.e.,* lead-cadmium) were not strongly correlated, suggesting that these elements do not share a common source in the analyzed fruits and vegetables (Alzahrani *et al.,* 2017). These findings highlight that the analyzed fruits and vegetables in Saudi Arabia during the study time were rich in sources of various essential nutrients, providing positive nutritional quality to these plants (Alzahrani *et al.,* 2017). Simultaneously, the poor correlations between certain metals suggest that their presence in these fruits is not a result of specific contamination or environmental change but rather from naturally occurring background concentrations (Alzahrani *et al.,* 2017).

Shotyk (2020) conducted a study using wild berries - *Arctostaphyles uva-ursi*, *Vaccinium myrtilloides*, *Vaccinium oxycoccos*, *Cornus stolonifera*, *Ribes sp.*, *Prunus pensylvanica*, *Rubus idaeus*, and *Rosa sp.* from reclaimed lands from open bitumen mining operations of Fort McMurray. The study revealed that TEs such as iron, lead, cobalt, manganese, etc., were

significantly and positively correlated with aluminum, which serves as an indicator of the abundance of dust particles on the berries (Shotyk, 2020). This suggests that these elements are primarily supplied by atmospheric dust deposition (Shotyk, 2020). In contrast, elements like copper, zinc, nickel, and molybdenum were not significantly correlated with aluminum, and their concentrations in the berries remained consistent across different berry species, suggesting that these elements are likely regulated by root uptake from the soil (Shotyk, 2020).

In addition to TEs, the release of organic compounds like PAHs into the environment, often originating from industrial emissions, has raised concerns (Al-Farhan *et al.,* 2023). Due to their hydrophobic nature, PAHs and their derivatives tend to accumulate significantly in plants (Al-Farhan *et al.,* 2023). While these compounds do not contribute to plant growth and development, their concentrations in fruits are measured as part of fruit quality assessment to ensure they do not surpass the optimal concentrations and to determine the source of these chemicals in the plants (Al-Farhan *et al.,* 2023).

Al-Farhan *et al.* (2023) investigated PAHs in a variety of fruits and vegetables that are commonly eaten in the Asir area, Saudi Arabia. They conducted correlation analyses to identify the potential sources of PAHs. The researchers suggested that strong positive correlations imply that these PAHs originate from similar sources (Al-Farhan *et al.,* 2023). Using diagnostic ratio/relationship indices, they were also able to determine whether these sources were pyrolytic (from combustion) or petrogenic (derived from petroleum) (Al-Farhan *et al.,* 2023). Other articles, such as Patel *et al.* (2020), have indicated that, in general, PAHs with 2 or more aromatic rings or high molecular weight are from pyrogenic sources, while PAHs with 2-3 fused aromatic rings or low molecular weight are from petrogenic sources (*i.e.,* crude oil). Therefore, measuring the association between

chemicals in plants helps determine the nutritional value of the plant, where the interaction between multiple essential elements suggests the presence of a variety of nutrients (Patel *et al.,* 2020). It also helps to identify whether these elements originate from similar or different sources, ensuring food safety and understanding the overall nutritional quality of the fruits (Patel *et al.,* 2020).

2. Metabolites

Phytochemicals, also known as phytonutrients, are biologically active, non-nutrient compounds produced by plants that provide various health benefits to consumers (Pott *et al.,* 2019). These phytonutrients, which include organic compounds used in a plant's metabolic processes or metabolites, are examined to assess plant quality (Pott *et al.,* 2019). Primary metabolism is indispensable for the plant's survival as it produces metabolites (*i.e.,* carbohydrates, lipids, and proteins) directly involved in plant growth and development (Pott *et al.,* 2019). On the other hand, secondary metabolism generates specialized compounds that, while not playing a primary role in basic plant functioning, are vital for defence, coloration, and other specific functions (Pott *et al.,* 2019). Although these secondary metabolites are significant for various plant processes, they are not essential for the plant's overall survival since primary metabolism remains the primary driver of essential growth and development processes (Pott *et al.,* 2019). Notably, plants producing fruits are particularly interesting since they contain high concentrations of secondary metabolites (Pott *et al.,* 2019; Health Canada, 2015). For example, blueberry species (*Vaccinium spp.*) are found to contain bioactive phytochemicals, such as anthocyanins, that serve as major secondary metabolites, with antioxidant properties that not only protect the plant from environmental stress but also provide health benefits to consumers (Health Canada, 2015; Yousef *et al.,* 2013). Mengist *et al.* (2020) highlighted that blueberry fruits (*Ericaceae* family and the genus *Vaccinium*) are

abundant in a wide range of bioactive metabolites, with a particular emphasis on flavonoids and phenolic acids, which are two major secondary metabolite groups. Of these metabolites, blueberries are particularly rich in anthocyanins, which are a type of flavonoid (Mengist *et al.,* 2020). These anthocyanins are primarily responsible for the vibrant colour of blueberries and are known to provide numerous health benefits to consumers (Mengist *et al.,* 2020). Green and Low (2013) compared the composition of different berries from Saskatchewan, Canada, where they found that chokecherries (*Prunus virginiana*), related to pin cherries as they both belong to the same genus, *Prunus*, had predominantly higher concentrations of anthocyanins compared to other metabolites (Green and Low, 2013). Therefore, the presence and high concentrations of secondary metabolites, especially those with antioxidant properties in plants, are regarded as highly beneficial for consumer health.

3. Antioxidants

Secondary metabolites in plants with antioxidant properties are of significant importance as they play a crucial role in enhancing the nutritional value of plants, providing protective functions to plants under stress and offering health benefits to consumers (Kasote *et al., 2015*). Reactive oxygen species (ROS) are naturally produced during aerobic metabolism in plants and act as signalling molecules and regulators of growth (Kasote *et al., 2015*). However, when plants encounter stress, such as exposure to excessive toxic metals resulting in poor soil quality, ROS production increases, leading to oxidative stress (Kasote *et al.,* 2015).

To counteract oxidative stress, plants increase their production of antioxidants, which are vital in scavenging and neutralizing free radicals, thus safeguarding cells from damage, and promoting plant survival (Iakovou and Kourti, 2022). Among antioxidants, there is a specific focus on non-enzymatic antioxidants, as consumers highly value them for their health benefits, including

reducing inflammation, supporting the immune system, and lowering the risk of chronic diseases (Iakovou and Kourti, 2022). Non-enzymatic antioxidants possess a unique ability to donate electrons to free radicals, effectively stabilizing and preventing oxidative damage (Iakovou and Kourti, 2022). Hence, researchers dedicate considerable attention to assessing the content of non-enzymatic antioxidants (Iakovou and Kourti, 2022). Consequently, this study specifically highlights non-enzymatic antioxidants, such as secondary metabolites (*e.g.,* phenolic compounds) and Vitamin C, which offer various health benefits to consumers (Iakovou and Kourti, 2022).

Phenolic Compounds

Phenolic compounds, also known as phenolics, are widely present in all parts of plants, including roots, leaves, and fruits (Dai and Mumper, 2010). These secondary metabolites play a crucial role in scavenging ROS, providing essential protective functions (Dai and Mumper, 2010). Zakłos-Szyda *et al.* (2019) demonstrated that phenolic compounds found in *Viburnum opulus* berries act as preventive agents against diet-related diseases like type 2 diabetes and obesity, which are associated with oxidative stress, impaired glucose uptake, and elevated concentrations of free fatty acids (Zakłos-Szyda*et al.,* 2019). The researchers observed that the phenolic-rich fraction of the berry extract reduced the uptake of glucose and fatty acids in Caco-2 cells without compromising their viability (Zakłos-Szyda*et al.,* 2019). Additionally, they found a decrease in the expression of the CD36/FAT gene, responsible for fatty acid transportation, without affecting the transporters responsible for glucose uptake (GLUT2 and PPARα) (Zakłos-Szyda*et al.,* 2019). These findings support the antioxidant role of phenolic compounds, which can mitigate diet-related chronic diseases by combating induced oxidative stress and improving metabolic health (Zakłos-Szyda *et al.,* 2019).

Among the diverse array of phenolics, flavonoids are a prominent group extensively studied (Liu *et al.,* 2018). Among them, anthocyanins stand out as they are highly abundant in human diets and contribute to the vibrant and attractive colours of various fruits (Liu *et al.,* 2018). Research has demonstrated the potent health benefits of anthocyanins, such as cyanidin-glycoside, which are commonly found in berry fruits like blueberries (Liu *et al.,* 2018). For example, studies have indicated that consuming purified anthocyanin mixtures reduced inflammation in patients with hypercholesterolemia (Zhu *et al.,* 2013) and improved endothelial function, as well as reduced inflammation in obese rats (Klimis-Zacas *et al.,* 2016). Moreover, Pilolla *et al.* (2023) recommend wild blueberries for active individuals, as these berries can help reduce oxidative stress and enhance the rate of fat oxidation during rest time, providing fatty acids for energy production. In their study, healthy rats that were moderately active exhibited an increased rate of fat oxidation when fed wild blueberries containing 375 g/d of anthocyanins for 2 weeks, compared to when the same group of rats was fed foods low in anthocyanins (Pilolla *et al.,* 2023). These findings emphasize the significant role of phenolic compounds, particularly anthocyanins, as essential contributors to the nutritional quality of fruits due to their various health benefiting roles (Pilolla *et al.,* 2023).

Vitamin C

Ascorbic acid, commonly known as Vitamin C (or its negatively charged ion, ascorbate), are also phytonutrients that is a crucial enzyme cofactor in various biosynthetic pathways within plants (Gest *et al.,* 2013). For instance, Gest *et al.* (2013) suggested that ascorbate plays a significant role as a cofactor in oxygenase enzymes, specifically those involved in the biosynthesis of flavonoids, including anthocyanins. The presence of ascorbate is essential for preventing the over-oxidation of iron ions at the enzymes' active sites (Gest *et al.,* 2013). Therefore, it is considered vital for

stabilizing these enzymes or the compounds themselves, such as anthocyanins (Gest *et al.,* 2013). Ascorbate may also function as a redox signal, facilitating the accumulation of anthocyanins (Gest *et al.,* 2013). Additionally, ascorbate is an antioxidant, capable of donating electrons to reduce radicals, effectively scavenging and neutralizing ROS (Gest *et al.,* 2013).

The FDA recommends a daily intake of 90 mg of Vitamin C for adults and children over 4 years old due to its numerous health benefits, including anti-inflammatory and immune-supporting effects (Kim *et al.,* 2018). Meeting this requirement can be achieved by consuming fruits that are low in calories but rich in Vitamin C (Kim *et al.,* 2018). Kim *et al.* (2018) evaluated the antioxidant properties of various well-known fruits (commercially bought) from South Korea, including *Aronia melanocarpa* (chokecherry), *Vaccinium uliginosum L.* (blueberry), *Prunus pauciflora Bunge* (cherry), *Vaccinium macrocarpon Aiton* (cranberry), *Garcinia mangostana* (mangosteen), *Schisandra chinensis Baillon* (omija), *Nephelium lappaceum* (rambutan), *Rubus idaeus L.* (raspberry), and *Fragaria grandiflora Duch* (strawberry). Their findings indicated that blueberries had the highest concentration of vitamin C content, followed by chokecherries, highlighting the richness of Vitamin C in berries and underscoring its significance as an indicator of nutritional quality (Kim *et al.,* 2018). Furthermore, Poiana *et al.* (2010) conducted a study comparing commercial blueberries (*Vaccinium myrtillus*), red raspberries (*Rubus idaeus*), and blackberries (*Rubus fruticosus*) from Romania. After freezing the berries for 10 months, they observed that blueberries exhibited the smallest percentage loss of vitamin C (23% loss in blueberries and 38% loss in blackberries). This finding indicates that blueberries are an excellent source of Vitamin C as they retain their concentrations even after extended storage periods (Zhu *et al.,* 2013; Klimis-Zacas *et al.,* 2016; United States Department of Health and Human Services, 2021; Bilska *et al.,* 2019).

Overall, plant antioxidants like phenolics and Vitamin C serve as indicators of plant nutritional quality. As phytonutrients, they primarily offer health benefits to consumers from a human health perspective, providing advantages beyond the basic nutritional contributions of macro and micronutrients. While nutrients also give insights into the plant's nutritional status, they do so from a physiological standpoint, being essential for plant growth and health.

4. Physicochemical Properties

Physicochemical properties, such as moisture content and pH, influence the overall physical appearance and quality of plants (Paniagua *et al., 2013*; Yadav and Singh, 2014; Lufu *et al., 2020*). Moisture content, which refers to the water content in fruits, can affect various aspects, such as swelling, wilting, firmness loss, weight loss, and changes in colour and flavour (Paniagua *et al., 2013*; Yadav and Singh, 2014; Lufu *et al., 2020*). Excessive moisture content can also lead to spoilage (Paniagua *et al.,* 2013; Yadav and Singh, 2014; Lufu *et al.,* 2020). On the other hand, pH, which determines the acidity or basicity of the fruit, plays a significant role in determining taste (Cohen *et al.,* 2014). To reduce the quality loss of *Vaccinium corymbosum L.* (highbush blueberries) during storage, Tong *et al.* (2018) explored the combined impact of two non-thermal technologies: vacuum impregnation (VI) and electron beam irradiation. These pre-treatments have been utilized to extend shelf life, improve texture, and reduce microbial decay (Tong *et al.,* 2018). The results indicated that blueberry samples subjected to VI exhibited no significant ($p > 0.05$) negative effects on quality attributes, such as moisture content, colour, pH, and phenolics, even after 14 days of storage compared to untreated berries (control) (Tong *et al.,* 2018). Moreover, the treated fruits retained their firmness, indicating improved texture compared to the control (Tong *et al.,* 2018). Therefore, assessing physicochemical properties alongside antioxidants is crucial to comprehensively evaluate the overall nutritional quality of plants (Tong *et al.,* 2018).

H. Soil-plant relationship

Soil-plant chemicals

Plants primarily obtain TEs, including both nutrients and metals, through their root system from the soil. The uptake and accumulation of these elements in plants are influenced by various factors, such as the concentrations and types of chemicals present in the soil and the soil's physicochemical properties (Foucher, 2011; Kabata-Pendias, 2004; Zhang and Shan, 2000). As a result, academic models often consider the uptake, bioavailability, and mobility of TEs by plants as functions of soil conditions (Foucher, 2011; Kabata-Pendias, 2004; Zhang and Shan, 2000). This is particularly concerning for toxic metals because, like nutrients, they are also present in the soil but at lower concentrations (Foucher, 2011; Kabata-Pendias, 2004; Zhang and Shan, 2000). Depending on the soil condition, these metals could become bioavailable, be taken up by roots, and accumulate in the plants (Foucher, 2011; Kabata-Pendias, 2004; Zhang and Shan, 2000). Conversely, these soil conditions could also influence the bioavailability of elements in the plant (Foucher, 2011; Kabata-Pendias, 2004; Zhang and Shan, 2000). Liu *et al.* (2020) investigated the influence of soil factors on mineral nutrients in *Ephedra intermedia*. They found positive correlations ($p < 0.05$) between macro and certain micronutrients in the plant and corresponding elements in the soil, with iron, manganese, and zinc in the soil showing the most significant associations (Liu *et al.,* 2020). Soil properties like CEC and sand also positively correlated with specific mineral nutrients in the plant, particularly iron. The PCA results revealed that silt, nitrogen, potassium, zinc, and molybdenum ($r > 0.7$) were the primary factors in the soil influencing *Ephedra intermedia* growth and quality (Liu *et al.,* 2020). Similarly, a separate PCA showed that nitrogen, potassium, zinc, copper, boron, molybdenum, and iron ($r > 0.7$) were the primary minerals driving the main variation in *Ephedra intermedia* data (Liu *et al.,* 2020). Therefore, these findings indicate that mineral nutrients in *Ephedra intermedia* are directly influenced by the TEs present in the soil, and certain soil

properties and minerals play a crucial role in the nutrient accumulation and growth of this plant (Liu *et al.,* 2020). Liu *et al.* (2021) conducted a study in Xinjiang Uygur Autonomous, Northwest China, examining the contamination status of TEs in soils and crops (grains, vegetables, melons, and fruits). They found that certain metals like lead and metalloids such as arsenic in the soil correlated with their content in crops, indicating the same potential pollution source and potential risks due to the influence of these chemicals on the bioavailability of metals and metalloids in crops (Liu *et al.,* 2021). Moreover, pH and CEC were strongly associated with arsenic, cadmium, and lead, which are priority elements known for their high toxicity, suggesting that these soil properties significantly affect the content of priority elements in crops (Liu *et al.,* 2021; Tchounwou *et al.,* 2012). Hence, investigating the link between different soil factors and TEs in plants is crucial to determining the quality status of the soil and the surrounding plants within an area (Liu *et al.,* 2021).

Studies such as Vorobets *et al.* (2021) have demonstrated strong correlations between elements in soil and their content in small shrubs, including blueberries (*Vaccinium corymbosum L.*) and bog billberry (*Vaccinium uliginosum L.*) in the study region of Ukraine. This research observed strong positive correlations ($r > 0.6$; $p < 0.05$) between zinc, manganese, and chromium concentrations in the soil and their content in different parts, particularly the fruits, of both berry species (Vorobets *et al.,* 2021). Furthermore, they observed strong negative correlations ($r < -0.7$; $p < 0.05$) between soil and the upper parts of the berries, indicating a direct connection between soil and the bioavailability of elements in the berries (Vorobets *et al.,* 2021).

Moreover, Stachiw *et al.* (2019) observed that certain elements, such as cadmium, copper, molybdenum, nickel, and zinc, which did not show strong correlations with lithophile elements (typically found on the surface of berries as dust particles), were taken up by berry plants

(*Vaccinium oxycoccus*, *Vaccinium vitisidaea*, and *Vaccinium myrtilloides*) from the soil near the bitumen mines and upgraders in Fort McKay and Fort McMurray areas in Alberta. This provides evidence of TEs present near the OS activity areas being absorbed by berry plants (Stachiw *et al.,* 2019). Berries hold significant importance in the traditional diets of Indigenous peoples in Canada, serving not only as a source of food but also as medicine (*e.g.,* certain berries are prepared as juice or tea and provided to women during childbirth to prevent post-partum hemorrhage) and fuel (*e.g.,* branches from berry bushes are used to smoke-dry the berries) (Boulanger-Lapointe *et al.,* 2019; Beausoleil *et al.,* 2022; Obomsawin, 2007; Nielsen *et al.,* 2020; Kuhnlein and Turner, 1991). As a result, the impact of soil changes on berries is a topic of significant interest, particularly among Indigenous communities in Northern Alberta (Boulanger-Lapointe *et al.,* 2019; Beausoleil *et al.,* 2022; Obomsawin, 2007; Nielsen *et al.,* 2020; Kuhnlein and Turner, 1991).

Soil-Antioxidants

1. Trace Elements & Antioxidant Content

Changes in soil conditions can have a significant impact on the concentrations of metabolites with antioxidant properties in plants (Das and Roychoudhury, 2014). Environmental factors, especially alterations in TE exposure, primarily at excessive concentrations in the soil, can influence the antioxidant content in various plant parts, including fruits, thereby affecting the overall nutritional quality (Das and Roychoudhury, 2014). As plants absorb TEs from the soil, take them up through their roots, and transport them within their tissues, these elements can accumulate or undergo metabolic processes, potentially leading to oxidative stress (Navabpour *et al.,* 2020; Das and Roychoudhury, 2014). In response, plants activate their defence mechanisms, allowing compounds with antioxidant properties to build up and counteract oxidative damage (Navabpour *et al.,* 2020; Sharifi-Rad *et al.,* 2020; Das and Roychoudhury, 2014). However, when stress becomes excessive,

it may overwhelm the defence system, resulting in reduced concentrations of antioxidants and negative consequences for the plant, such as DNA damage and cell death (Huang *et al.,* 2019; Navabpour *et al.,* 2020; Sharifi-Rad *et al.,* 2020; Das and Roychoudhury, 2014).

For instance, studies by Wang *et al.* (2022) revealed that muskmelon (*Cucumis melo L.*) seeds' anthocyanin content peaked at 50 mg/kg cadmium exposure but decreased at 200 mg/kg. Marmiroli *et al.* (2017) found that tomato (*Solanum lycopersicum L.*) fruits exposed to arsenic had lower total phenolic content compared to the control, with differences depending on the cultivar. Kısa *et al.* (2016) observed that the total phenolic content in corn (*Zea mays convar. saccharata var. rugosa*) increased under 10 ppm exposure to trace elements like copper, lead, and cadmium but decreased at 50 ppm exposure. Groth *et al.* (2017) demonstrated that selenium biofortification in apples (*Malus domestica*) had both positive and negative effects on antioxidant concentrations, depending on the form of selenium applied. Kumar *et al.* (2022) discovered that sweet potatoes (*Ipomoea batatas L.*) exposed to chromium at low concentrations (25 µM) increased antioxidant content, but higher exposure concentrations (50-200 µM) displayed deleterious effects. Mittal *et al.* (2017) observed reduced growth but enhanced phenolic content in broad beans (*Vicia faba L.*) exposed to nickel, cobalt, and iron. Sabatino *et al.* (2019) found that tomato (*Solanum lycopersicum L.*) plants with an enhanced molybdenum supply had increased phenolic and ascorbic acid content in their fruits. Conversely, Khalofah *et al.* (2021) demonstrated that toxic mercury stress decreased anthocyanin concentrations in fenugreek (*Trigonella foenum-graecum*).

The impact of TEs on plant antioxidant content, whether positive or negative, can vary based on factors such as concentration, specific elements or their combinations, and plant species (Groth *et al.,* 2017; Kumar *et al.,* 2022; Mittal *et al.,* 2017; Sabatino *et al.,* 2019; Khalofah *et al.,* 2021).

Thus, these factors should be considered when assessing the influence of TEs on antioxidants in plants (Groth *et al.,* 2017; Kumar *et al.,* 2022; Mittal *et al.,* 2017; Sabatino *et al.,* 2019; Khalofah *et al.,* 2021).

2. PAHs & Antioxidant Content

The interaction between PAHs and antioxidants in plants has been studied, but there is limited knowledge about this association when exposed via the soil (Shen *et al.,* 2018; Lagos *et al.,* 2021). Unlike essential elements, PAHs are not required for plant growth and development (Lagos *et al.,* 2021). However, when present in the soil, PAHs can be taken up by plant roots, leading to oxidative stress in plants, which triggers the accumulation of antioxidants to activate their defence system (Lagos *et al.,* 2021). The extent of the impact of PAHs on antioxidants (positive or negative) depends on various factors, especially the concentration of PAHs in the soil (Lagos *et al.,* 2021). For example, Alwan (2015) conducted a study using Waterthymes aquatic plants (*Hydrilla vertcillata*) exposed to different concentrations of phenanthrene and pyrene (10, 50, 100, 150, 200 µg/L) in a nutrient solution. They found that ascorbic acid content in the leaves increased as the concentration of the two PAH compounds increased. Although this study did not compare the differences in the leaves with other parts of the plants (*i.e.,* roots), it is likely that the PAHs were taken up from the roots to the leaves through the nutrient solution, as supported by existing literature (Alwan, 2015). Jiang *et al.* (2017) conducted a pot experiment using black mangrove (*Aegiceras corniculatum (L.) Blanco (Ac)*), exposing the plants to cadmium (0, 0.5, 1.0, 2.0, and 4.0 mg/L) and phenanthrene (a PAH) treatments (0, 0.25, 0.50, 0.75, and 1.0 mg/L). They observed that exposure to both contaminants enhanced the concentration of total phenolic compounds in the leaves and roots. The leaves had higher concentrations of phenolics, but lower concentrations of both chemicals compared to the roots. Nikzad and Parastar (2021) conducted a study with lettuce

(*Lactuca sativa L.*) seeds exposed to a nutrient solution containing a mixture of PAHs (including anthracene, pyrene, acenaphthene, and acenaphthylene) at different concentrations (10 to 100 µg/L). They found that as the PAH concentrations increased in the treatment groups, the total phenolic content and total antioxidant activity in the leaves decreased. However, even with these negative effects on antioxidants, the exposed groups still had higher concentrations of antioxidants than the non-exposed groups within the tested concentration range. These studies suggest that exposure to certain PAHs via soil can lead to impacts on the antioxidant content of plants, particularly changes in phenolics.

3. Soil Properties & Antioxidants

Soil properties are influenced by natural and human-related factors, leading to changes in their concentrations. For instance, Liu *et al.* (2017) investigated the impact of surface mining and reclamation on soil properties in the Pingshuo coal mine in China. They found that most reclaimed mine soil properties, such as pH, phosphorus, and potassium, increased, while organic matter and nitrogen decreased compared to natural soil. These alterations affect the availability of elements and organic pollutants (*i.e.,* PAHs) for plants, with the specific impacts varying based on the type of compound and soil property (Liu *et al.,* 2017). Zhang *et al.* (2017) discussed that increased soil pH results in more negatively charged soil particles, attracting positively charged ions to the surface. This leads to the binding of positively charged elements like zinc, cadmium, nickel, and copper to the soil particles, thereby reducing their bioavailability for plant uptake. Moreover, less hydrophobic PAHs are less likely to be adsorbed by SOM due to their hydrophobic functional groups, making them more bioavailable for plants as they have less tendency to remain in the surface soils (Sushkova *et al.,* 2020). Consequently, increased bioavailability of PAHs in the soil may result in their higher uptake by plants.

Numerous studies have demonstrated the impact of soil properties on the antioxidant content of plants. Liu *et al.* (2021) found that the vitamin C content in inbred "SJ11-3" peppers (*Capsicum*) is likely influenced by soil chemical properties, particularly the available potassium content. The exact pathway remains unclear, but it is believed that potassium uptake by plants affects the accumulation of vitamin C in their tissues. Bedbabis *et al.* (2015) showed that long-term irrigation with treated wastewater altered soil properties (increased pH, electrical conductivity, organic matter), leading to a gradual decrease in total phenolic content in olive (*Olea europaea*) plants after 10 years of treatment. Wang *et al.* (2019) indicated that applying cow manure vermicompost and soil at different ratios (0:7, 4:7 to 7:0 w/w) enhanced vitamin C, total phenolic content, and antioxidant activity concentrations in Chinese cabbage (*Brassica campestris ssp. Chinensis*) plants up to the 4:7 mixture but decreased at the 7:0 treatment. This change is likely attributed to the increased concentrations of SOM, total nitrogen, total phosphorus, electrical conductivity, water holding capacity, and soil pH between the 4:7 and 7:0 treatments.

The interaction between changes in soil properties and the concentration of antioxidants in plants is complex. Alterations in soil chemical concentrations can lead to plant stress and the formation of ROS, prompting the activation of antioxidants, which ultimately affects the concentrations of antioxidants in plants (Liu *et al.,* 2017; Dutta *et al.,* 2018; Singh *et al.,* 2020). For instance, Natasha *et al.* (2022) demonstrated that adding biochar amendments to soil can modify physicochemical soil properties, leading to increased nutrient bioavailability and immobilization of toxic elements. This reduces the uptake of toxic elements by plants, mitigates oxidative stress, and enhances antioxidant activity (Natasha *et al.,* 2022). Consequently, plant growth improves due to reduced toxicity, plant physiology is enhanced, and plant yield increases (Natasha *et al.,* 2022). These

findings underscore the significance of considering soil properties when assessing the antioxidant content and nutritional quality of plants (Liu *et al.,* 2017; Dutta *et al.,* 2018; Singh *et al.,* 2020).

4. Plant Physicochemical Properties & Antioxidants

In addition to soil physical and chemical factors influencing the antioxidant content in plants, additional research has highlighted the association between antioxidants and the physicochemical characteristics within the plant itself (Paniagua *et al.,* 2013; Yadav and Singh, 2014; Lufu *et al.,* 2020). This dynamic interplay among soil factors, antioxidants, and plant physicochemical factors not only affects the nutritional quality of the plant but also significantly contributes to its appearance, flavour, and other characteristics, ultimately influencing the overall quality of the plant (Paniagua *et al.,* 2013; Yadav and Singh, 2014; Lufu *et al.,* 2020).

To better comprehend the factors impacting the overall fruit quality, numerous studies have delved into the relationship between the physicochemical properties of plants and their antioxidant content (Paniagua *et al.,* 2013; Yadav and Singh, 2014; Lufu *et al.,* 2020). In a study by Mello and Quadros (2014), a strong positive correlation ($r > 0.8$) was observed between the pH of green tea (*Camellia sinensis*) and its ability to counteract oxidative stress, as indicated by total antioxidant capacity (TAC). However, it is essential to approach these correlations with caution and refrain from assuming causality solely based on them. Although an increase in pH seems to coincide with a rise in TAC, indicating higher antioxidant capacity, they also found a negative influence ($r < -0.9$) on the concentration of phenolic compounds (TPC) in the fruit. Similarly, Baek and Shin (2020) demonstrated a positive correlation ($r > 0.8$) between both the pH and moisture content of the edible part of mini paprika (*Capsicum annum*) and its total phenolic content. While pH showed a

positive correlation ($r > 0.7$) with the overall ability of these paprikas to scavenge free radicals (Total antioxidant activity or TAA), moisture content exhibited a negative correlation with TAA (Baek and Shin, 2020). Furthermore, Yan *et al.* (2021) illustrated that compared to ripe jujube (*Ziziphus jujuba Mill.)* fruit cultivars, unripe fruits are characterized by high concentrations of ascorbic acid, total phenolic content, phenolic compounds, and total antioxidant activities. They further discovered that moisture content in these fruits is negatively correlated with all these antioxidants (Yan *et al.,* 2021). Studies suggest that the negative association with moisture content is likely due to the overproduction of ROS, resulting in a reduction of TPC at high moisture content, leading to chilling injury in the fruits (Mediani *et al.,* 2014). Conversely, low moisture content, such as in dried fruits stored at proper temperatures, can prevent or slow down the natural decomposition of antioxidants, such as phenolics (Mediani *et al.,* 2014). Additionally, low moisture content can trigger the activation of compounds involved in TAC and TPC in the plant, as the cell wall becomes fragile (Mediani *et al.,* 2014).

CHAPTER 1.1 RATIONALE AND OBJECTIVES

Pin cherry (*Prunus pensylvanica L.F.*) and common blueberry (*Vaccinium myrtilloides Michx*) are two plant species commonly found in boreal forests, and they are well-adapted to the region's climatic and soil conditions (Tirmenstein, 1990). Pin cherry plants generally thrive in well-drained soils that are slightly acidic (pH < 7) and can tolerate a range of soil textures, including sandy soil (Anderson, 2004). In contrast, common blueberry plants prefer acidic, moist, and well-drained soils that are rich in organic matter. They typically grow best in soils with a pH between 3.0 and 5.9, which are commonly found in peatlands (Tirmenstein, 1990). These plants provide ecological benefits, such as habitat and food for wildlife, as well as a food source for local communities, including the Fort McMurray First Nations and Métis communities. For generations, these communities have traditionally utilized pin cherries for making jams, jellies, and sauces. At the same time, Common blueberries have been frequently consumed as a fresh snack or incorporated in baked goods (Kuhnlein and Turner, 1991).

Although blueberries are known to be rich in antioxidants, there have been no peer-reviewed studies conducted on the antioxidant composition and potential health benefits of pin cherries (Kalt *et al.,* 2020). However, related species such as chokecherry (*Prunus virginiana*), which belong to the same genus as pin cherries (*Prunus*) and the *Rosaceae* family, have been found to have similar nutritional values and are high in antioxidants, such as cyanidin 3-glucoside, a major anthocyanin commonly found in colourful berries (Anderson, 2004; Li *et al.,* 2008).

The main objective of this master's thesis is to investigate the relationship between environmental conditions (including chemical profiles and physical properties in soil and plants) and berry health

metrics in select sites in the AOSR. Specifically, the research aims to achieve the following objectives:

a) Identify the main factors driving pin cherry and blueberry fruit and soil quality from sampled sites in 2022.
b) Determine whether the concentration of chemicals (TEs, and parent and alkylated-PAHs) in the sampled soil influence the concentrations of chemicals in the sampled pin cherry and blueberry fruits.
c) Determine which environmental conditions including TEs and PAH concentrations, and the physicochemical properties in soil and/or plants, are related to the concentration of antioxidants in sampled pin cherries and blueberries in 2022.

CHAPTER 2. METHODOLOGY

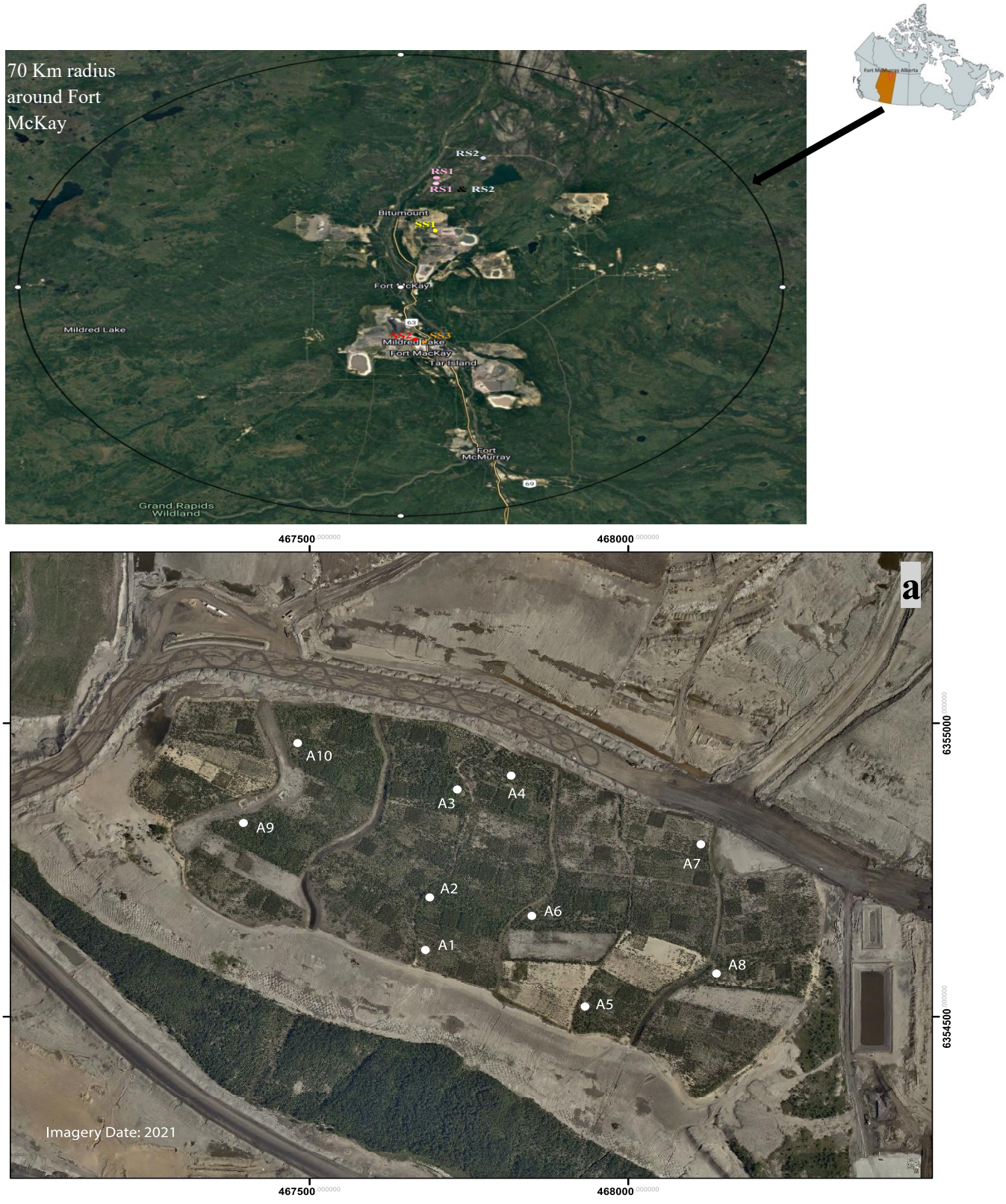
A. Species and site selection*:* The target fruit species for this study were the common blueberry (*Vaccinium myrtilloides Michx*) and pin cherry (*Prunus pensylvanica L.F.*), both of which are shrubs, characterized as woody plants generally smaller than trees (Götmark *et al.,* 2016) (Figure 2). These two species differ from each other in several ways: blueberry shrubs produce blue-coloured fruits when ripe and typically have an average height of 4-35 inches (Tirmenstein, 1990), while pin cherry shrubs produce red-coloured cherry fruits when ripe and are considerably taller, reaching an average height of 12 meters (Flora database, n.d.).

Figure 2: Images of pin cherry (*Prunus pensylvanica L.F.*) (on the left) and common blueberry (*Vaccinium myrtilloides Michx*) (on the right) from selected sites (OS reclaimed and natural) in and near Fort McMurray, Alberta. Captured by Chathumi De Silva.

The specimens were collected from four different locations in or near Fort McMurray, Alberta. Three of these locations are reclamation sites under the jurisdiction of Syncrude OS: the Aurora Soil Capping Study (Study Site 1 or SS1), located at the currently operating Aurora North OS mine

operations in Fort McMurray (Figure 3A) (COSIA, 2020); the Sandhill Fen Research Watershed (Study Site 2 or SS2), located north of the East In-Pit deposit (a former mine that was actively mined from 1978-2000 and is currently filled with OS deposits for reclamation) (Figure 3B); and the Kingfisher Fen (Study Site 3 or SS3), located immediately next to Sandhill Fen (Figure 3B) (Environmental assessment, n.d.; COSIA, 2020; Syncrude Canada Ltd, 2020).

The Aurora site was planted with trees in 2012. While most of the Sandhill sites were intentionally left unplanted, although some areas where fruits were collected were planted with trees in 2013. The Kingfisher site was planted with canopies in 2016. These sites, therefore, are relatively young and have undergone reclamation. The fourth location selected was a remote natural site located near the Fort Chipewyan winter road staging areas along Highway 63, over 30 km away from the Syncrude OS activities in Fort McMurray. This site is referred to as Natural Site 1 (RS1) for pin cherry and Natural Site 2 (RS2) for common blueberry. Pin cherry and common blueberry samples were collected from this site, and their corresponding locations (RS1 and RS2) are shown in Figures 3C and D (Farnden and Yarmuch, 2022).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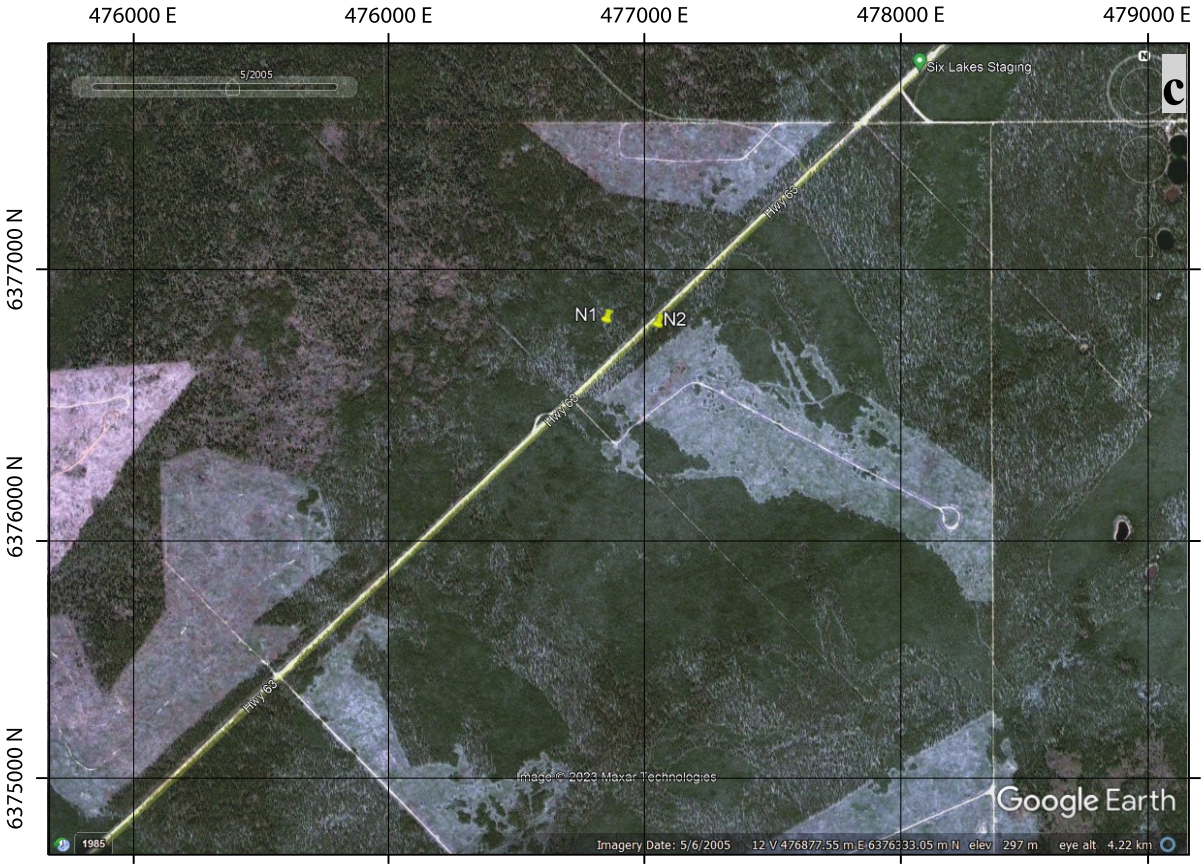
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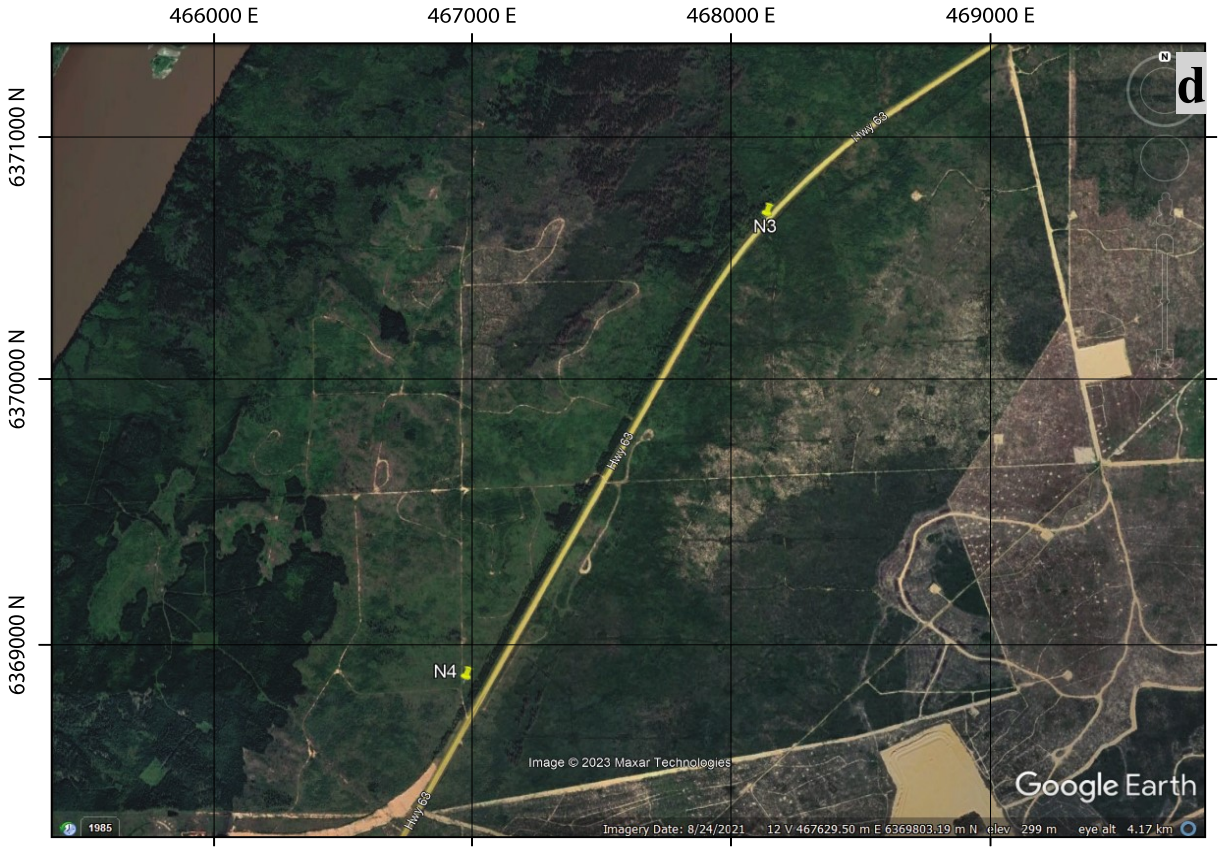

Figure 3: Illustrates maps (A-D) displaying the corresponding Universal Transverse Mercator (UTM) easting (E) and northing (N) coordinates of the locations where pin cherry and common blueberry fruits, and their coupled soil samples, were collected in and near Fort McMurray, Alberta. **Image A** indicates the areas where pin cherry samples (A1 to A10) from Reclaim Site 1 (SS1) were collected. **Image B** represents the areas where pin cherry samples (S1 to S10) from Reclaim Site 2 (SS2) were collected, as well as the areas where common blueberry samples (K1 to K6) from Reclaim Site 3 (SS3) were collected. **Image C** indicates the areas where common blueberry samples (N1 and N2) were collected from Natural Site 2 (RS2). **Image D** represents the areas where pin cherry (N3 and N4) and common blueberry (N4) samples were collected from Natural Sites 1 and 2 (RS1 and RS2).

B. Site characteristics: The variations in soil layers and conditions between and within each studied site were determined in the areas where the pin cherries and blueberries were picked.

In the Aurora site (SS1), only pin cherries were collected. The soil composition consisted of a 10-30 cm layer of peat on top, followed by a 10-20 cm layer of coarse-textured upland surface soil, such as used litter, fermentation, humus (LFH) upper layer, and near-surface mineral soil as the

underlying subsoil (USS). This was further followed by 100-140 cm of coarse-textured subsoil with lean OS substrate (Figure 4A).

In the Sandhill reclaimed site (SS2), pin cherries were collected. The soil consisted of a 15 cm layer of coarse-textured USS cover soil, followed by a 30 cm layer of fine-textured subsoil, and 2-3 meters of tailings sand and composite tailings substrates.

In the Kingfisher reclaimed site (SS3), blueberries were collected. The cover soil layer was 37 cm in size from the surface and consisted of coarse-textured USS on top, followed by a 26 cm layer of fine-textured subsoil and 2-3 meters of coarse tailings sand cap and composite tailings substrates beneath (Figure 4B).

As indicated by Farnden and Yarmuch (2022), the soil samples collected from the natural sites were primarily sandy textured and showed characteristics of low nutrient content and low organic matter (Figure 4C).

Figure 4: Illustrates soil samples collected in conjunction with pin cherry and common blueberry plants at Reclaim Site 1 (SS1) where pin cherry samples were collected (A), at Reclaim Site 3 (SS3) where common blueberry samples were collected (B), and at Natural Site 2 (RS2) where common blueberry samples were collected (C). The samples were collected on August 9th and 10th, 2022, and the images were captured by Chathumi De Silva.

C. Sample collection: During the period from August 9th to August 12th, 2022, blueberry, and pin cherry specimens, along with corresponding soil samples, were collected from both Syncrude OS reclaimed and natural sites. The selection of these sites was decided by the Syncrude OS research and development group, and the exact UTM (Universal Transverse Mercator) easting and northing coordinates of these locations are provided in figure 3A-D. The samples were hand-collected primarily by the Syncrude OS research group, consisting of two Syncrude researchers and three undergraduate co-op students, following a specified protocol that was provided by the principal researcher/author of this study. As a visitor, the author was not authorized to collect samples from the reclaimed sites but had the opportunity to collect some blueberry specimens from the natural site (not under Syncrude jurisdiction).

The collection of fruit and soil samples followed a protocol supported by the literature. At each site, multiple quadrats were randomly selected per species, with the number of quadrats varying depending on the availability of each species (*e.g.,* one quadrat per sample). The size of each quadrat was difficult to determine, given the inconsistent distribution and availability of each species, but most of the quadrats measured over 600 m^2. The collection was performed using nitrile gloves, which were changed between samples. At each quadrat, fruits from multiple plants per species and corresponding soil samples were collected and divided into two separate containers: a glass jar with a polytetrafluoroethylene or Teflon (PTFE)-lined lid (for Polyaromatic compounds (PACs) analysis) and a zip-lock bag (for the rest of the analyses, including trace elements). Approximately 10 g and 150 g of fruit and 40 g and 400 g of soil per sample were respectively placed into glass jars and zip-lock containers. The amount of samples varied based on the availability of the species at each quadrat. In both the reclaimed and natural sites, there were specimens, particularly blueberries, that were either ripe or unripe (green in colour), with some variations among individual plants. Therefore, both ripe and unripe specimens were pooled together as one sample.

The soil collection protocol involved collecting two sets of 4-5 soil sub-samples from each quadrat per site. One set of soil was collected using a steel shovel and placed in glass jars with PTFE lids, while the other set was collected using a plastic shovel and placed in zip-lock bags. The shovels were thoroughly cleaned with distilled water and dried with clean J-cloths between each sample collection. Each soil sub-sample measured approximately 2 cm x 5 cm horizontal by 10 cm vertical (for natural sites, it was approximately 10-20 cm), with 2 cm of the top surface layer scraped off to remove any thatch, mulch, roots (>0.5 mm diameter), or woody debris. At the end of the collection, the samples were tightly packed and shipped to their respective locations. The fruit and soil samples in glass jars were sent to an accredited commercial laboratory called the Centre for Oil and Gas Research and Development (COGRAD) at the University of Manitoba, which specializes in Polycyclic Aromatic Compounds (PACs). The samples in zip-lock bags were sent to the University of Ottawa. They arrived in good condition a few days after shipment.

Upon arrival at the labs, each fruit sample was handled with nitrile gloves, and was thoroughly rinsed (3x) with water and dried on J-cloths/Kim-wipes for 10 minutes to remove any dust. The air-dried blueberry and pin cherry specimens were placed in biohazard bags (whirl-pack) and tightly sealed. Both the fruit samples in the biohazard bags and soil samples in zip-lock bags were stored in a -20°C freezer until further analysis. In early November 2022, all the samples that were already stored in the -20^0C freezer were shipped to an accredited commercial agriculture and food laboratory at the University of Guelph to analyze the trace elements of both fruits and soil samples, as well as the chemical and physical properties of soil samples. They also arrived in good condition a few days after shipment.

Due to the limited availability of pin cherry and common blueberry species at both reclaimed and natural sites in Fort McMurray during the sample collection period, a total of 37 fruit samples were analyzed in this study, 6 blueberries from SS3, 7 blueberries from RS2, 10 pin cherries from SS1,

10 pin cherries from SS2, and 4 from RS1. Additionally, 31 soil samples were analyzed, comprising 10 samples from SS2, 10 samples from SS1, 6 samples from SS3, 2 samples from RS1 and 3 samples from RS2. The limited availability of species during the sample collection period resulted in a small sample size, which should be noted.

D. Chemicals and Soil Physicochemical Properties Analysis:

Polycyclic Aromatic Hydrocarbons (PAHs) Analysis:

The PAHs analyses for the samples in this study were conducted by the accredited commercial lab at the University of Manitoba, as detailed below:

Polycyclic aromatic compound (PAC) analysis in both berries and sediment samples was conducted at the Centre of Oil and Gas Research and Development (COGRAD, University of Manitoba, Winnipeg, Canada); an ISO17025 and CALA-accredited facility. Fisher Chemical™ Optima™ grade high-purity solvents, Fisher Scientific™ silica gel (923 grade, 100-200 mesh), alumina (60-325 mesh), Ottawa sand, copper, and diatomaceous earth (DE), were used for sample extraction. The suite of labelled recovery internal standards (RIS) used for isotope dilution of PAC includes d_8-naphthalene, d_8-acenaphthylene, d_{10}-acenaphthene, d_{10}-fluorene, d_{10}-phenanthrene, d_{10}-pyrene, d_{12}-benz[a]anthracene, d_{12}-chrysene, d_{12}-benzo[b]fluoranthene, d_{12}-benzo[k]fluoranthene, d_{12}-benzo[a]pyrene, d_{12}-indeno[1,2,3-c,d]pyrene, d_{14}-dibenz[a,h]anthracene, and d_{14}-benzo[g,h,i]perylene (Cambridge Isotope Laboratories Inc. (Tewsbury, Massachusetts, USA). Mass-labeled (d_{10}) anthracene was used as the instrument performance internal standard (IPIS) (Accustandard Inc. New Haven, Cincinnati, USA). Further, standard reference material (SRM) such as 1944 New York and New Jersey waterway sediment was purchased from the National Institute of Standards and Technology (Gaithersburg, MD, USA).

Briefly, 0.5 g wet samples (soils and berries) were homogenized with 1.5 g diatomaceous earth following the procedure in Xia *et al.* (2019) and extracted with dichloromethane (DCM) via accelerated solvent extraction (ASE Dionex 350; at 125 °C and 1500 psi, 6 min heating time, 5 min static time and 2 cycles). Samples underwent a one-step extraction method following Xia *et al.* (2019) to improve laboratory efficiency and reduce the volume of organic solvent used. After extraction, the extract was treated with sodium sulphate to remove moisture and subsequently reduced to 5 mL in a round bottom flask. IPIS was added to a concentration of 100 pg/µL in the sample. An Agilent 7890 gas chromatograph coupled with a triple quadrupole mass spectrometer fitted with an electron ionization (EI) source was used for the acquisition of MS/MS spectra using an Agilent J&W HP-5 ms ultra inert column (30 m × 0.25 mm × 0.25 µm), with helium as the carrier gas at a constant flow rate of 1.2 mL/min. Sample (1 µL) was injected with a PAL RSI 85 autosampler at 250°C in splitless mode. Further GC/MS/MS and MRM conditions are outlined in Idowu *et al.* (2018).

Trace Elements (TEs) and Soil Properties analyses:

The accredited commercial lab at the University of Guelph conducted the analyses for trace elements and soil physicochemical properties of the berry and soil samples in this study, as outlined below:

TEs:

Trace element analysis in both berries and sediment samples was conducted at the University of Guelph, Laboratory Services Division; an ISO17025 and CALA-accredited facility. The methods followed USEPA Method 3051A Microwave Assisted Acid Digestion of Sediments, Sludges, Soils and Oils and USEPA Method 6020B Inductively Coupled Plasma – Mass Spectrometry

(Element, 2007; CASRN, 2014). Briefly, the digestion of samples was conducted on a Multiwave 3000 microwave reaction system (Anton Paar USA), equipped with temperature and pressure control. The ICP-MS system was a Perkin-Elmer NexIon 300D with an ESI SC-8XC high throughput FAST autosampler. Representative samples were frozen into a pre-weighed 150 mL cup and freeze-dried. Moisture content was determined. The microwave digestion was carried out in closed vessels at 180 ± 5˚C for 10 minutes using 0.5 g of a well-mixed sample with the addition of 1 mL of distilled deionized water (DDW), 5 mL of concentrated HNO_3, and 1 mL of concentrated hydrofluoric acid (SeaStar Chemicals Inc). The digested solutions were diluted to 100 mL using DDW before ICP-MS analysis. For quality control, blanks were run and deemed adequate when measured with less than three times the method detection limit (MDL) for each analyte. The relative percent difference of the duplicates was maintained within 20%. The internal standard percent recovery and the recoveries of the Independent Calibration Verification (ICV) and the Continuing Calibration Verification (CCV) standards were assessed and within 80-120%. Certified reference materials (CRM, peach and citrus leaves - National Institute of Standards and Technology (NIST), Gaithersburg, MD) were also be provided to the lab for QA/QC to assess the quality and validity of the results.

Electrical conductivity (EC):

The EC meter was used to measure the salinity of soil, manure, waste, and solution samples received in SNL. Samples were prepared as follows: Soils were dried at 35^{o}C and sieved to <2mm. Waste, manure, and solution samples were analyzed 'as received', but were extracted as necessary. Soils, wastes, and manures were analyzed using a 2:1 (volume: volume) extract, while solutions were analyzed 'as received'. Greenhouse media were extracted using a saturated paste extract. Analysis was performed at room temperature (Greenberg *et al.,* 1992).

Particle size distribution (pipette method):

Particle size analysis measured the proportions of the various sizes of primary soil particles (silt, clay, sand, and gravel) as determined by their capacities to pass through sieves of various sizes and by their rates of settling in water using the principle of sedimentation known as Stoke's Law (Sheldrick and Wang, 1993).

Soil pH:

pH was read on a saturated paste, or on an 'as received' basis if the sample was sufficiently moist. Buffer pH was analyzed on soils having a pH of 6.0 or less and was used to determine how much lime was required on farm soils (Hendershot *et al.,* 1993).

Potassium and magnesium (extractable):

Samples were extracted using a 1.0N Ammonium Acetate solution, and the concentrations of K, and Mg were determined using an ICP-OES. Analysis was done on a mass or volume basis. Fertilizer recommendations were based on mg/L Soil results, and therefore Farm Fertility and other Farm tests were always done volumetrically (Simard, 1993).

Phosphorus:

Sodium bicarbonate-extractable phosphorus also referred to as Olsen P, was commonly used to measure plant available P in Ontario soils. Samples were extracted using a 0.5M sodium

bicarbonate solution, and the concentration of P in the extract was determined colourmetrically using a Seal AA3 (Reid, 1998).

Nitrogen (Leco):

The Leco CN828 was used to measure the total nitrogen content in soil, plant, waste, and other samples. This instrument provided elemental analysis of nitrogen (N) and carbon (C). Inorganic carbon (IC) was determined by ashing the sample at 475 °C for 3 hours before carbon analysis using catalytic combustion (950°C); the desired components were separated from the combustion gases and analyzed using thermal conductivity detection and infrared detection. Organic carbon was calculated by subtracting the inorganic carbon result from the total carbon result.

Cation Exchange Capacity (CEC):

CEC was determined by saturating the exchange sites in the soil with a single cation (Ba+) and then displacing it with a different cation ($NH4^{+}$). The amount of the original cation (Ba+) that was displaced from the soil was then measured to calculate the CEC (Rhoades, 1982).

Heavy Metals in Soils by ICPMS

Soil and other matrices were dried, ground, and extracted using mixed acid microwave digestion to remove organics and solubilize trace metals. The extraction was only partial. The silicates were not broken down, leaving elements bound in the silicate matrices intact. Care had to be taken during digestion to avoid the formation of insoluble oxides. The extract was brought to volume with Nanopure water. The clear extract supernatant was measured by Inductively-coupled plasma mass spectrometry (ICP-MS) for Cd, Cr, Co, Cu, Mo, Ni, Pb, Zn, Hg, As, and Se (EPA, 2004; CASRN, 2014).

Soil Moisture:

The soil moisture content was expressed by weight as the ratio of the mass of water present to the dry weight of the soil sample. The criterion for a dry soil sample was the soil sample that had been dried to constant weight in an oven at 105°C. This temperature range was based on the water boiling temperature and did not consider the soil's physical and chemical characteristics (Black, 1965).

Organic Matter (Loss on Ignition method):

Loss on Ignition described the removal of organic matter and other volatiles by ashing the sample at 425ºC. LOI was reported as a percentage of dry sample. Organic Matter LOI (OMLOI) was a direct measure of soil organic matter content as described in the "Soil Fertility Handbook, OMAFRA Publication #611, 3rd edition" (OMAFRA, 2018).

E. Fruits Physicochemical Analysis:

pH and water content in fruits

To measure pH in the fruits, approximately 2 g of fruit per sample (includes reclaimed, and natural blueberries and pin cherries) was blended with 30 ml of distilled water for 5 minutes at medium speed. The pH of each sample was then measured using a pH meter.

To determine the moisture content of all fruit samples, approximately 2 g of frozen fruit per sample was placed in a food dehydrator (NESCO PROFESSIONAL Food and Jerky Dehydrator) at 57°C for a duration of 24 hours. The weight of the fruit (per sample) before and after drying was measured using a weighing balance to determine the water content in the fruits. The weight of the fruit, including the container (*i.e.,* filter cup), was recorded before drying, and the weight of the

fruit, including the same container, was recorded after drying. The difference between the two weights yielded the water content in fruits, expressed in grams/grams (g/g).

$$\text{Water Content (WC)} = \frac{wet\ weight\ (g) - dry\ weight\ (g)}{wet\ weight\ (g)}$$

F. Total Vitamin C content in fruits

To determine the total vitamin C content in fruit samples, the 2,4-dinitrophenyl hydrazine (DNPH) method was employed as described by Riemschneider *et al.* (1976) with the English version by Khan *et al.* (2006). The method involves the coupling reaction of the DNPH dye with vitamin C, followed by spectrophotometric determination.

To prepare the fruit sample extract, ≈ 5 g of blueberry fruits (per sample) were blended with 50 mL of 5% metaphosphoric-10% acetic acid (medium speed for 5 minutes), while pin cherry fruits (per sample) were shaken using magnetic balls in a capped tube to remove the seeds and ensure that the berry juice is not lost to obtain ≈ 5 g of fruits. All homogenized fruits were measured on a balance and blended with 50 mL of metaphosphoric-acetic acid (medium speed for 5 minutes). Each blended sample was placed in an ultrasonic bath for 30 minutes at 25°C, followed by centrifugation at 5000 RPM, 25°C for 20 minutes. The supernatant (per sample) was poured off and filtered using Whatman #1 paper.

To estimate the vitamin C content in the samples, an aliquot (1 mL) of each extract was mixed with 3 mL of metaphosphoric-acetic acid solution, followed by the addition of 400 µL of bromine water to change the colour to light yellow, 50 µL of 10% thiourea to remove the bromine, and 1

mL of the DNPH reagent (in the fume hood). Mixtures were vortexed and incubated at 37°C for 3 hours. After the incubation period, the solutions were placed in an ice bath for 2-3 minutes (freshly prepared 85% sulfuric acid (H_2SO_4) was also on the ice bath to cool). 5 mL of H_2SO_4 was added to each cooled solution. The residues should dissolve immediately to give either an intense or less red colour, depending on the level of vitamin C present in the sample. The absorbances were read (analyzed in triplicates/per sample) on Synergy HTX 96-well microplate reader at 521 nm. A standard solution of ascorbic acid (range 0-40 µg/mL) was used to construct the calibration curve presented in the appendix Figure 7. The results were expressed as mg per 100 g of fresh weight (FW) of the fruit.

The required reagents were prepared as follows: 5% metaphosphoric acid-10% acetic acid was prepared by mixing 60 g of solid metaphosphoric acid in 160 mL of glacial acetic acid. The mixture was diluted with Milli-Q ultrapure water (resistivity of 18.2 MΩ·cm) until the 2 L mark in a flask. Bromine water was prepared by mixing 5 mL of bromine with 100 mL of Milli-Q, shaking vigorously, and filtering using Whatman filter paper (#1). The 10% thiourea solution was prepared by mixing 5 g of thiourea with Milli-Q to make the total volume to 50 mL. The 85% H_2SO_4 was prepared by slowly adding 170 mL of H_2SO_4 to 30 mL of Milli-Q water in the fume hood. The DNPH reagent was prepared by mixing 3 g of DNPH, 20 mL of Milli-Q water, and 70 mL of 95% ethanol in a flask, and 15 mL of H_2SO_4 was added slowly when the solution reached 10^0C. If the temperature went above 20^0C, the addition of H_2SO_4 was stopped until the temperature dropped to 10^0C. Once all the H_2SO_4 was added, the mixture was heated until 60^0C, the heating was turned off and the mixture was stirred until cooled.

G. Polyphenolic Analyses

Sample Preparation

For the determination of polyphenolic content and antioxidant capacity, 5 g of blueberry and pin cherry (seeds removed) samples were weighed using a balance and homogenized in 25 mL of Milli-Q water (use of water as the extraction solvent was based on literature evidence) using a blender (Marjanovic *et al.,* 2021). The resulting mixtures were then placed in an ultrasonic bath at 25 °C for 30 minutes to facilitate extraction. Subsequently, each sample extract was centrifuged at 4,000 RPM for 20 minutes at 22°C, and the supernatants were filtered using Whatman filter paper (#1). All procedures were conducted in accordance with established laboratory protocols.

Total Phenolic content (TPC)

Total phenolic content (TPC) was determined using the Folin-Ciocalteu spectrophotometric method as described by Singleton *et al.* (1999). A 20 µL aliquot of each sample extract was added to a mixture of 0.1 mL of Folin-Ciocalteu reagent with 1.58 mL of Milli-Q water. Following an 8-minute waiting period, 0.3 mL of 20% aqueous sodium bicarbonate solution was added to the mixture, followed by incubation at 40°C for 30 minutes. The samples and standards (triplicates per sample) were measured at 750 nm against the blank on a Synergy HTX 96-well microplate reader. Tannic acid standards (100-1000 mg/L) were used to construct a calibration curve, which is presented in the appendix (Figure 8). Results were expressed as mg Tannic acid equivalent per g of fresh weight.

Total anthocyanins content (TAnC)

The pH-differential method, as described by Lee *et al.* (2005), was employed to determine the total monomeric anthocyanins in the blueberry and pin cherry samples. Specifically, 1 mL of each sample extract was mixed with 3 mL of 0.025 M potassium chloride at pH 1.0, while another 1 mL aliquot was mixed separately with 3 mL of 0.4 M sodium acetate at pH 4.5. Both mixtures were then incubated at room temperature for 15 minutes, and the absorbances of each sample in potassium chloride and sodium acetate reagents were measured at 520 nm and 700 nm, respectively, using a Synergy HTX 96-well microplate reader. TAnC results were expressed as cyanidin-3-glucoside equivalents mg per 100 g of fresh weight (FW) using the equation provided in the appendix (Equation 1).

For the preparation of the reagents, 0.4 M sodium acetate at pH 4.5 was prepared by mixing 9.84 g of sodium acetate with Milli-Q water, bringing the total volume to 150 mL. Then, 75 mL of the diluted sodium acetate was additionally diluted with Milli-Q water to reach a final volume of 150 mL. Hydrogen chloride (HCl) was added to the mixture in drops to set the pH to 4.5. Similarly, a potassium chloride solution with a concentration of 0.025 M at pH 1.0 was made by mixing 2.80 g of potassium chloride with Milli-Q water to a total volume of 150 mL. Subsequently, 15 mL of the diluted potassium chloride was added to Milli-Q water to reach a final volume of 150 mL, and HCl was slowly added ($\leq$ 200 µL) to the mixture to bring the pH to 1.0. The pHs of both solutions were measured using a pH meter.

Total Antioxidant Activity (TAA)

The antioxidant activity was measured using the Ferric-reducing antioxidant power (FRAP) assay. Specifically, 50 µL of each sample extract was mixed with 1.5 mL of FRAP reagent, and the absorbances were measured at 620 nm using a Synergy HTX 96-well microplate reader against a

blank of 50 µL distilled water and 1.5 mL FRAP reagent. The calibration curve was constructed using Trolox standards (0.2-3.2 mM) (Appendix Figure 9). The results were expressed as µmol Trolox equivalent/g FW.

The FRAP reagent was prepared as follows: Firstly, 0.28 M acetic acid was prepared by mixing 1.6 mL of acetic acid with Milli-Q water up to the 100 mL mark, followed by the addition of 2.46 g of sodium acetate to the solution, resulting in a final volume of 100 mL. To bring the pH down to 3.6, HCl (≤ 1 mL) was slowly and dropwise added to the sodium acetate-acetic acid mixture. Next, 40 mM HCl was prepared by mixing 61.7 µL of HCl with Milli-Q water up to the 50 mL mark, and this solution was mixed with 0.156 g of TPTZ to obtain a TPTZ stock solution of 10 mM. In addition, 0.270 g of FeCl3 was mixed with Milli-Q water (Final volume = 50 mL) to obtain a stock solution of 20 mM $FeCl_3 \times 6\ H_2O$. Finally, the FRAP reagent was prepared by mixing 7.5 mL of 10 mM TPTZ solution, 75 mL of 300 mM acetate buffer at pH 3.6, and 7.5 mL of 20 mM $FeCl_3$ solution (1:10:1).

Total Antioxidant Capacity (TAC)

The phosphomolybdate method, as described by Prieto *et al.* (1999), was used to measure TAC. Briefly, 0.3 mL of each sample extract was mixed with 3 mL of the phosphomolybdate reagent. The solution was then incubated at 95°C for 90 minutes, and the absorbances were measured at 695 nm using a Synergy HTX 96-well microplate reader against a blank containing 0.3 mL of Milli-Q water and 3 mL of the phosphomolybdenum reagent. A calibration curve was constructed using ascorbic acid standards (10-1000 mg/L) (Appendix Figure 10). The results were expressed as mg ascorbic acid/g FW.

To prepare the phosphomolybdenum reagent, the following stock solutions (A, B, and C) were first prepared: A) 6 M sulphuric acid: 30 mL of sulphuric acid was slowly added to 20 mL of Milli-Q water. B) 0.28 M sodium phosphate (dibasic): 3.75 g of sodium phosphate (dibasic) was mixed with Milli-Q water (final volume = 50 mL). C) 0.04 M ammonium molybdate: 2.47 g of ammonium molybdate was mixed with Milli-Q water, totaling the volume to 50 mL. Finally, 15 mL of each stock solution (6 M sulphuric acid, 0.28 M sodium phosphate, and 0.04 M ammonium molybdate), totaling to 45 mL, was mixed with Milli-Q water, totaling the final volume to the 150 mL mark. This provided concentrations of 0.6 M sulphuric acid, 28 mM sodium phosphate, and 4 mM ammonium molybdate, forming the phosphomolybdate reagent.

H. Statistical Analysis

The data were analyzed using the XLstat extension for Microsoft Excel 365, version 16.66.1 software. They were organized by berry type, sample type, and site type. Bar graphs were generated to visualize mean concentrations and the margin of error at the 95% confidence interval. Before proceeding with in-depth statistical analysis, the normality of each variable was examined. These variables were grouped as:

- Trace Elements (TEs)
- Alkylated-PAHs
- Parent-PAHs
- Soil properties
- Fruit quality variables

Further categorization was based on berry type and sample type (soil or fruit). For pin cherries, data from sites SS1, SS2, and RS1 were combined, and for blueberries, data from sites SS3 and RS2 were pooled together. The Kolmogorov–Smirnov test was utilized to check the normality for each set of data. Variables yielding a p-value < 0.05 in the test, indicating either positive (> 1 statistic) or negative skewness (< -1 statistic), underwent a log10 transformation. On the other hand, if the p-value was > 0.05, the variable was not transformed as it fit the normal distribution. Subsequent analyses utilized both the transformed and untransformed data.

Statistical tools such as Pearson Correlation, Scatter plots, Linear Regression and Principal Component Regression (PCR), and Principal Component Analysis (PCA) with accompanying biplots were employed to investigate the associations between analyzed variables in fruit and soil samples specific to each berry type, provide insights into linear relationships between various soil and fruit variables, explore the relationship between variables in each sample type per berry type, as well as between antioxidants and other environmental parameters in the samples (Appendix Tables 1-23 and Figures 1-6).

CHAPTER 3. RESULTS

A. Concentrations in soil and berry samples

Tables 1-2 (a and b) display the descriptive statistics for concentrations of environmental variables, corrected for detection limits (See appendix Tables 14-18 for method detection limits), assessed in this study. These variables include trace elements (TEs; measured in mg/kg dry weight), polycyclic aromatic hydrocarbons (including both parent and alkylated forms; measured in ng/g dry weight), soil physicochemical properties, and fruit quality variables such as antioxidants and physicochemical properties. The data are derived from soil samples of pin cherry (Table 1a), fruit samples from pin cherry (Table 1b), soil samples from blueberry (Table 2a), and fruit samples from blueberry (Table 2b). These samples were collected from selected sites (SS1, SS2, SS3, RS1, and RS2) in Fort McMurray. The statistics provided are designed to emphasize patterns observed across sites and berry types, showcasing comparisons of mean concentrations and ranges for each variable.

As illustrated in Table 1a for pin cherry soil, number of samples (N) per site varied, with 2 from RS1 and 10 each from SS1 and SS2, resulting in a total of 22 pin cherry soil samples (without replicates) analyzed for this study. Among these sites, SS2 exhibited the highest mean concentrations for 35 chemicals of predominantly individual and total parent and alkylated PAHs and TEs, except for sand, P, and moisture. In contrast, RS1 displayed the lowest mean concentrations for 31 elements and hydrocarbon compounds, excluding sand, P, K, moisture, and N. Total Hg was consistent across all three sites with a concentration of 0.02 mg/Kg, indicating no concentration differences between these sites, especially when reported to two decimal places. Other chemicals, such as cadmium and selenium, showed comparable concentrations between SS1

and RS1. The broadest concentration range was observed in total alkylated PAHs (335.95 and 540.97 ng/g) in SS1 and SS2 samples respectively,. On the other hand, the narrowest concentration ranges pertained to TEs (0.00 mg/Kg), including cadmium, total mercury, and selenium in samples from RS1 and SS1 (mercury). This implies a high degree of consistency in samples from these sites, remaining within the same range when rounded to two decimal places.

Table 1a: Descriptive statistics for trace elements (mg/kg dry weight), polycyclic aromatic hydrocarbons (parent and alkylated; ng/g), and properties of pin cherry Soil samples from Oil Sands Reclaimed (SS1, SS2) and Natural (RS1) sites in Fort McMurray, Alberta.

Groups (Units)	Variables	Sites	N	Concentration Range	Mean Concentration	Standard error of the mean
Trace Elements (mg/Kg)	Arsenic	RS1	2	0.29	1.06	0.10
		SS1	10	0.70	1.68	0.08
		SS2	10	1.71	1.51	0.18
	Cadmium	RS1	2	0.00	0.03	0.00
		SS1	10	0.03	0.03	0.00
		SS2	10	0.06	0.04	0.01
	Chromium	RS1	2	0.40	5.20	0.14
		SS1	10	2.90	5.51	0.20
		SS2	10	12.10	6.92	1.27
	Cobalt	RS1	2	0.50	1.55	0.18
		SS1	10	0.90	1.74	0.10
		SS2	10	4.15	2.20	0.43
	Copper	RS1	2	0.40	1.30	0.14
		SS1	10	1.50	1.74	0.14
		SS2	10	5.10	3.06	0.53
	Lead	RS1	2	0.30	2.25	0.11
		SS1	10	0.70	2.40	0.07
		SS2	10	4.00	3.04	0.43
	Mercury	RS1	2	0.00	0.02	0.00

		SS1	10	0.00	0.02	0.00
		SS2	10	0.01	0.02	0.00
	Molybdenum	RS1	2	0.05	0.36	0.02
		SS1	10	0.34	0.41	0.02
		SS2	10	0.24	0.46	0.03
	Nickel	RS1	2	0.50	3.95	0.18
		SS1	10	2.40	4.74	0.21
		SS2	10	8.90	6.21	0.95
	Selenium	RS1	2	0.00	0.08	0.00
		SS1	10	0.00	0.08	0.00
		SS2	10	0.14	0.11	0.02
	Zinc	RS1	2	2.00	16.00	0.71
		SS1	10	9.10	12.93	0.83
		SS2	10	17.10	14.47	1.76
Alkylated PAHs (ng/g)	Total APAHs	RS1	2	66.63	161.12	23.56
		SS1	10	474.28	335.95	43.73
		SS2	10	356.47	540.97	42.00
	C1 Chrysene	RS1	2	3.67	6.27	1.30
		SS1	10	36.96	27.09	3.12
		SS2	10	42.71	65.99	5.05
	C1 Dibenzothiophene	RS1	2	0.95	0.53	0.34

		SS1	10	10.66	3.87	0.99
		SS2	10	10.70	9.04	1.04
	C1 Fluorene	RS1	2	2.45	1.23	0.87
		SS1	10	2.12	0.75	0.25
		SS2	10	2.25	0.82	0.29
	C2 Chrysene	RS1	2	3.52	14.26	1.24
		SS1	10	124.25	104.85	11.75
		SS2	10	144.14	211.05	16.08
	C2 Dibenzothiophene	RS1	2	2.45	4.65	0.87
		SS1	10	22.39	8.99	2.05
		SS2	10	17.97	15.16	1.83
	C2 Fluorene	RS1	2	3.77	4.28	1.33
		SS1	10	16.39	7.65	1.46
		SS2	10	7.72	7.29	0.67
	C2 Naphthalene	RS1	2	3.10	11.73	1.09
		SS1	10	9.60	3.85	0.83
		SS2	10	20.97	11.75	2.11
	C2 Phenanthrene	RS1	2	0.62	4.83	0.22
		SS1	10	15.96	11.51	1.38
		SS2	10	19.61	19.25	2.31
	C3 Chrysene	RS1	2	3.20	4.06	1.13

		SS1	10	12.32	6.05	0.85
		SS2	10	14.54	10.44	1.38
	C3 Dibenzothiophene	RS1	2	3.79	3.23	1.34
		SS1	10	16.97	6.81	1.57
		SS2	10	15.06	9.40	1.64
	C3 Fluorene	RS1	2	6.66	7.19	2.36
		SS1	10	38.51	17.56	3.59
		SS2	10	12.53	16.10	1.29
	C3 Naphthalene	RS1	2	1.12	5.75	0.39
		SS1	10	13.57	6.49	0.91
		SS2	10	15.13	12.16	1.70
	C3 Phenanthrene	RS1	2	12.45	14.64	4.40
		SS1	10	24.95	19.29	2.20
		SS2	10	31.86	24.22	2.98
	C4 Chrysene	RS1	2	2.56	3.82	0.91
		SS1	10	12.31	5.38	0.87
		SS2	10	14.23	7.96	1.36
	C4 Dibenzothiophene	RS1	2	7.46	25.65	2.64
		SS1	10	142.80	60.02	13.55
		SS2	10	125.23	63.76	12.24
	C4 Fluorene	RS1	2	3.56	4.88	1.26

		SS1	10	19.29	10.83	1.95
		SS2	10	7.87	8.25	0.66
	C4 Naphthalene (Butyl)	RS1	2	0.08	4.03	0.03
		SS1	10	6.25	5.46	0.49
		SS2	10	11.15	7.14	1.12
	C4 Phenanthrene	RS1	2	6.64	18.42	2.35
		SS1	10	24.66	19.75	2.22
		SS2	10	27.17	20.89	2.67
	Dibenzothiophene	RS1	2	0.37	0.26	0.13
		SS1	10	2.41	0.80	0.23
		SS2	10	4.19	2.89	0.51
	Retene	RS1	2	28.41	21.43	10.05
		SS1	10	49.24	9.92	4.05
		SS2	10	102.51	19.45	9.33
Parent PAHs (ng/g)	Total PAHs	RS1	RS1	2	8.41	11.79
		SS1	SS1	10	26.35	13.87
		SS2	SS2	10	24.26	28.49
	Acenaphthene	RS1	2	0.03	0.90	0.01
		SS1	10	1.58	1.16	0.22
		SS2	10	1.65	0.65	0.23
	Acenaphthylene	RS1	2	0.83	1.60	0.29

		SS1	10	1.37	0.40	0.13
		SS2	10	1.41	0.28	0.13
	Anthracene	RS1	2	0.82	0.67	0.29
		SS1	10	0.69	0.41	0.06
		SS2	10	1.17	1.22	0.13
	Benz[a]anthracene	RS1	2	0.26	1.35	0.09
		SS1	10	1.87	0.72	0.17
		SS2	10	3.42	3.89	0.39
	Benzo[a]pyrene	RS1	2	1.44	1.04	0.51
		SS1	10	3.17	1.03	0.29
		SS2	10	5.37	4.61	0.54
	Benzo[b]fluoranthene	RS1	2	0.89	0.74	0.32
		SS1	10	4.85	2.16	0.45
		SS2	10	2.15	2.80	0.23
	Benzo[g,h,i]perylene	RS1	2	0.47	0.42	0.16
		SS1	10	4.97	2.99	0.55
		SS2	10	3.76	4.67	0.37
	Benzo[k]fluoranthene	RS1	2	0.94	0.57	0.33
		SS1	10	1.95	0.84	0.20
		SS2	10	1.83	1.67	0.17
	Dibenzo[a,h]anthracene	RS1	2	0.12	0.06	0.04

		SS1	10	1.08	0.49	0.12
		SS2	10	1.33	1.56	0.15
	Fluoranthene	RS1	2	1.59	1.54	0.56
		SS1	10	2.05	0.87	0.19
		SS2	10	1.31	1.17	0.14
	Indeno[1,2,3-c,d]pyrene	RS1	2	0.60	0.43	0.21
		SS1	10	2.22	1.51	0.27
		SS2	10	1.54	1.85	0.16
	Pyrene	RS1	2	2.58	2.46	0.91
		SS1	10	3.64	1.28	0.35
		SS2	10	3.60	4.11	0.40
Soil Properties	CEC (cmol+/kg)	RS1	2	2.33	4.75	0.82
		SS1	10	7.87	5.86	0.79
		SS2	10	15.34	12.77	1.81
	EC (mS/cm)	RS1	2	0.01	0.06	0.00
		SS1	10	0.11	0.09	0.01
		SS2	10	0.14	0.12	0.01
	OM (% dry)	RS1	2	0.26	2.36	0.09
		SS1	10	2.45	2.49	0.24
		SS2	10	3.90	4.26	0.35
	Gravel (%)	RS1	2	0.00	0.10	0.00

		SS1	10	0.70	0.16	0.05
		SS2	10	2.40	0.84	0.24
	Sand (%)	RS1	2	3.20	91.70	1.13
		SS1	10	6.20	89.93	0.64
		SS2	10	52.80	75.95	5.44
	Silt (%)	RS1	2	3.20	5.80	1.13
		SS1	10	5.20	6.40	0.54
		SS2	10	24.30	11.81	2.44
	Clay (%)	RS1	2	0.00	2.50	0.00
		SS1	10	3.50	3.69	0.28
		SS2	10	28.60	12.25	3.04
	Phosphorus (mg/L soil dry)	RS1	2	6.00	18.00	2.12
		SS1	10	7.90	8.89	0.77
		SS2	10	10.20	6.47	0.92
	Potassium (mg/L soil dry)	RS1	2	10.00	43.00	3.54
		SS1	10	15.00	39.38	1.25
		SS2	10	84.00	75.42	8.20
	pH	RS1	2	1.40	5.90	0.49
		SS1	10	1.70	6.57	0.20
		SS2	10	0.80	6.83	0.08
	Moisture (% dry)	RS1	2	1.63	9.95	0.58

		SS1	10	2.54	2.24	0.24
		SS2	10	7.67	5.88	0.79
	Nitrogen (% dry)	RS1	2	0.03	0.07	0.01
		SS1	10	0.07	0.06	0.01
		SS2	10	0.17	0.13	0.01

N = Sample Size. Variables abbreviations: Arsenic = As; Cadmium = Cd; Chromium = Cr; Cobalt = Co; Copper = Cu; Lead = Pb; Mercury = Total Hg; Molybdenum = Mo; Nickel = Ni; Selenium = Se; Zinc = Zn; CEC = Cation Exchange Capacity; EC = Electrical Conductivity; OM = Organic Matter; Phosphorus = Total P; Potassium = Total K; Nitrogen = Total N

In Table 1b, the number of sampled pin cherry fruits varied among the sites: 4 from RS1, and 10 each from SS1 and SS2. SS1 samples exhibited the highest mean concentrations for various variables, predominantly individual and total hydrocarbons—mostly alkylated compounds—along with certain TEs such as Cr, Co, Mg, Zn, Se, and Ni. This site also displayed the highest mean concentrations for fruit variables like TAnC, TAC, and pH. Conversely, RS1 samples had the lowest mean concentrations for these, as well as additional fruit variables such as TAA, TPC, and water content.

Several individual PAHs, like Benzo[a]pyrene, and specific TEs, namely As, Hg, and Se, displayed consistent concentrations across these sites when rounded to two decimal places. Also As, Hg, and Se were reported as not detected in the fruit samples. Suggesting their concentrations were negligible after two decimal places.

Some PAHs and TEs showcased comparable concentrations between pairs of sites. For instance, RS1 and SS2 yielded similar concentrations, as did SS1 and SS2. The largest concentration variances for variables, like Mg and Vitamin C, were primarily observed in samples from SS1 and SS2. Meanwhile, RS1 displayed minimal concentration differences (0.00) for multiple variables, predominantly TEs and a few PAH compounds—with 12 variables showing no range at all.

Moreover, when comparing the same berry type's soil samples, the mean concentration of the majority of analyzed chemicals was substantially higher in the soil than in the fruit samples from the studied sites. For example, the mean total APAHs in RS1 soil and fruit samples were 161.12 ng/g and 6.73 ng/g, respectively.

Table 1b: Descriptive statistics for trace elements (mg/kg dry weight), polycyclic aromatic hydrocarbons (parent and alkylated; ng/g), and fruit quality variables of pin cherry fruit samples from Oil Sands Reclaimed (SS1, SS2) and Natural (RS1) sites in Fort McMurray, Alberta.

Groups (Units)	Variables	Sites	N	Concentration Range	Mean Concentration	Standard error of the mean
Trace Elements (mg/Kg)	Arsenic	RS1	4	0.00	0.00	0.00
		SS1	10	0.00	0.00	0.00
		SS2	10	0.00	0.00	0.00
	Boron	RS1	4	0.30	4.30	0.03
		SS1	10	12.70	12.22	1.16
		SS2	10	16.00	13.40	1.59
	Chromium	RS1	4	0.00	0.01	0.00
		SS1	10	0.01	0.02	0.00
		SS2	10	0.02	0.01	0.00
	Cobalt	RS1	4	0.00	0.00	0.00
		SS1	10	0.00	0.01	0.00
		SS2	10	0.01	0.00	0.00
	Copper	RS1	4	0.55	1.30	0.13
		SS1	10	1.08	1.32	0.10
		SS2	10	2.00	1.89	0.19
	Iron	RS1	4	4.00	6.83	0.90
		SS1	10	2.90	5.82	0.28
		SS2	10	4.90	7.15	0.47
	Magnesium	RS1	4	60.00	244.67	9.98

		SS1	10	130.00	350.66	12.78
		SS2	10	230.00	350.14	22.01
	Mercury	RS1	4	0.00	0.00	0.00
		SS1	10	0.00	0.00	0.00
		SS2	10	0.00	0.00	0.00
	Molybdenum	RS1	4	0.02	0.04	0.00
		SS1	10	0.02	0.01	0.00
		SS2	10	0.04	0.02	0.00
	Nickel	RS1	4	0.02	0.07	0.00
		SS1	10	0.06	0.08	0.01
		SS2	10	0.07	0.07	0.01
	Selenium	RS1	4	0.00	0.00	0.00
		SS1	10	0.01	0.00	0.00
		SS2	10	0.00	0.00	0.00
	Zinc	RS1	4	0.80	2.39	0.16
		SS1	10	1.70	3.03	0.17
		SS2	10	1.30	3.02	0.11
Alkylated PAHs (ng/g)	Total APAHs	RS1	4	10.63	6.73	2.06
		SS1	10	116.66	51.48	11.69
		SS2	10	20.99	9.52	2.05
	C1 Chrysene	RS1	4	0.12	0.15	0.02

		SS1	10	1.18	0.70	0.12
		SS2	10	0.36	0.15	0.04
	C1 Dibenzothiophene	RS1	4	0.14	0.04	0.03
		SS1	10	2.37	0.87	0.23
		SS2	10	0.44	0.18	0.04
	C1 Fluorene	RS1	4	0.05	0.01	0.01
		SS1	10	2.54	0.62	0.26
		SS2	10	1.05	0.15	0.10
	C2 Chrysene	RS1	4	0.38	0.51	0.06
		SS1	10	4.93	2.06	0.44
		SS2	10	1.56	0.53	0.16
	C2 Dibenzothiophene	RS1	4	0.71	0.32	0.15
		SS1	10	13.24	5.62	1.32
		SS2	10	1.77	0.96	0.17
	C2 Fluorene	RS1	4	0.17	0.04	0.04
		SS1	10	4.81	1.77	0.60
		SS2	10	1.20	0.26	0.11
	C2 Naphthalene	RS1	4	4.77	3.03	1.12
		SS1	10	8.93	1.48	0.68
		SS2	10	2.17	0.49	0.25
	C2 Phenanthrene	RS1	4	0.65	0.38	0.12

		SS1	10	13.09	4.82	1.15
		SS2	10	1.16	0.98	0.12
	C3 Chrysene	RS1	4	0.00	0.00	0.00
		SS1	10	0.73	0.17	0.06
		SS2	10	0.17	0.06	0.02
	C3 Dibenzothiophene	RS1	4	0.68	0.26	0.15
		SS1	10	14.79	6.07	1.53
		SS2	10	1.75	1.08	0.17
	C3 Fluorene	RS1	4	0.28	0.06	0.06
		SS1	10	6.67	2.34	0.86
		SS2	10	2.01	0.26	0.19
	C3 Naphthalene	RS1	4	0.14	0.08	0.03
		SS1	10	1.46	0.56	0.17
		SS2	10	0.71	0.09	0.07
	C3 Phenanthrene	RS1	4	2.82	1.57	0.55
		SS1	10	10.27	4.97	1.14
		SS2	10	2.35	1.40	0.24
	C4 Chrysene	RS1	4	0.00	0.00	0.00
		SS1	10	0.09	0.02	0.01
		SS2	10	0.01	0.00	0.00
	C4 Dibenzothiophene	RS1	4	1.87	0.77	0.43

		SS1	10	47.91	16.45	5.26
		SS2	10	7.73	2.58	0.69
	C4 Fluorene	RS1	4	-	-	-
		SS1	10	4.01	2.07	0.46
		SS2	10	0.95	0.44	0.07
	C4 Naphthalene (Butyl)	RS1	4	0.05	0.03	0.01
		SS1	10	0.94	0.25	0.10
		SS2	10	0.06	0.01	0.01
	C4 Phenanthrene	RS1	4	0.15	0.06	0.03
		SS1	10	2.59	1.24	0.30
		SS2	10	0.62	0.28	0.05
	Dibenzothiophene	RS1	4	0.00	0.03	0.00
		SS1	10	0.33	0.11	0.04
		SS2	10	0.21	0.05	0.02
	Retene	RS1	4	0.05	0.05	0.01
		SS1	10	0.76	0.31	0.06
		SS2	10	0.15	0.07	0.02
Parent PAHs (ng/g)	Total PAHs	RS1	4	0.76	0.44	0.14
		SS1	10	0.30	0.68	0.02
		SS2	10	0.27	0.67	0.02
	Acenaphthene	RS1	4	0.05	0.08	0.01

		SS1	10	0.32	0.09	0.03
		SS2	10	0.30	0.12	0.04
	Acenaphthylene	RS1	4	0.00	0.06	0.00
		SS1	10	0.00	0.06	0.00
		SS2	10	0.04	0.05	0.01
	Anthracene	RS1	4	0.01	0.04	0.00
		SS1	10	0.04	0.04	0.00
		SS2	10	0.02	0.04	0.00
	Benz[a]anthracene	RS1	4	0.05	0.02	0.01
		SS1	10	0.05	0.04	0.01
		SS2	10	0.06	0.05	0.01
	Benzo[a]pyrene	RS1	4	0.05	0.05	0.01
		SS1	10	0.05	0.05	0.01
		SS2	10	0.05	0.05	0.00
	Benzo[b]fluoranthene	RS1	4	0.06	0.03	0.01
		SS1	10	0.05	0.02	0.00
		SS2	10	0.00	0.03	0.00
	Benzo[g,h,i]perylene	RS1	4	0.00	0.03	0.00
		SS1	10	0.03	0.03	0.00
		SS2	10	0.00	0.03	0.00
	Benzo[k]fluoranthene	RS1	4	0.05	0.03	0.01

		SS1	10	0.04	0.03	0.01
		SS2	10	0.00	0.04	0.00
	Dibenzo[a,h]anthracene	RS1	4	0.00	0.05	0.00
		SS1	10	0.00	0.05	0.00
		SS2	10	0.00	0.05	0.00
	Fluoranthene	RS1	4	0.09	0.07	0.02
		SS1	10	0.05	0.05	0.00
		SS2	10	0.04	0.05	0.00
	Indeno[1,2,3-c,d]pyrene	RS1	4	0.11	0.09	0.02
		SS1	10	0.00	0.11	0.00
		SS2	10	0.00	0.11	0.00
	Pyrene	RS1	4	0.14	0.05	0.03
		SS1	10	0.20	0.12	0.02
		SS2	10	0.04	0.05	0.00
Fruit Quality Variables	TAA (µmol Trolox equivalency/g)	RS1	4	32.48	49.38	6.75
		SS1	10	34.32	51.49	3.82
		SS2	10	21.42	54.97	2.10
	TAC (mg AA/g)	RS1	4	3.56	6.91	0.74
		SS1	10	9.85	9.75	0.78
		SS2	10	6.26	9.36	0.66
		RS1	4	13.10	11.81	2.73

	TAnC (cyanidin-3-glucoside equivalents, mg/L)	SS1	10	14.14	17.33	1.17
		SS2	10	12.12	15.50	1.24
	TPC (mg TAE/g)	RS1	4	10.91	20.33	2.17
		SS1	10	13.87	20.74	1.15
		SS2	10	14.85	23.03	1.55
	Vitamin C (mg per 100 g of fresh weight of the fruit)	RS1	4	80.13	179.07	14.20
		SS1	10	171.04	155.31	16.45
		SS2	10	123.74	138.43	11.79
	pH	RS1	4	0.09	3.42	0.02
		SS1	10	0.59	3.79	0.05
		SS2	10	0.32	3.72	0.04
	Water Content (g/g)	RS1	4	0.11	0.62	0.03
		SS1	10	0.26	0.74	0.02
		SS2	10	0.10	0.76	0.01

N = Sample Size. BD = Below Detection Limit. Variables abbreviations: Arsenic = As; Boron = B; Cadmium = Cd; Chromium = Cr; Cobalt = Co; Copper = Cu; Iron = Fe; Magnesium = Mg; Lead = Pb; Mercury = Total Hg; Molybdenum = Mo; Nickel = Ni; Selenium = Se; Zinc = Zn; TAnC = Toal Anthocyanin Content; TAA = Total Antioxidant Activity; TAC = Total Antioxidant Capacity; TPC = Total Phenolic Content.

NOTE: The concentration of C4 Fluorene at RS1 was below the detection limit, and there was no method detection limit (MDL) available for correction.

For blueberries, analyses were conducted on two selected sites. In terms of soil, we examined three samples from RS2 and six from SS3 (as detailed in Table 2a). For the sampled blueberry soil, the highest mean concentrations of all analyzed environmental variables were found in samples from SS3, as opposed to those from RS2. Broadest concentration ranges were mainly evident in samples from SS3, with total APAHs exhibiting a range of 2697.47 ng/g and specific individual APAHs, such as C1-C2 Chrysene, showing large variations. In contrast, some variables like gravel and Se in RS2 samples had a minimal range, with the lowest being 0.00.

When comparing these findings to those of sampled pin cherry soil from their respective sites, blueberry soil from RS2 displayed the highest concentrations for the majority of chemicals, including most individual and total hydrocarbons, as well as several properties (except for gravel, sand, and pH). On the other hand, soil from RS1 demonstrated the highest mean concentration of TEs, excluding Cd, and Zn. Certain TEs, specifically Se (0.08 mg/Kg), maintained consistent concentrations between RS1 and RS2. For reclaimed sites, SS3 samples had the predominant mean concentrations for chemicals, with exceptions being As, and specific properties excluding Gravel, Sand, Phosphorus, Potassium and pH compared to soil samples from SS1 and SS2.

Table 2a: Descriptive statistics for trace elements (mg/kg dry weight), and polycyclic aromatic hydrocarbons (parent and alkylated; ng/g), and properties of blueberry soil samples from Oil Sands Reclaimed (SS3) and Natural (RS2) sites in Fort McMurray, Alberta.

Groups (Units)	Variables	Sites	N	Concentration Range	Mean Concentration	Standard error of the mean
Trace Elements (mg/Kg)	Arsenic	RS2	3	0.21	0.83	0.07
		SS3	6	0.90	1.65	0.11
	Cadmium	RS2	3	0.02	0.04	0.01
		SS3	6	0.07	0.10	0.01
	Chromium	RS2	3	1.00	4.53	0.33
		SS3	6	6.50	10.82	0.83
	Cobalt	RS2	3	0.20	1.23	0.07
		SS3	6	1.70	2.82	0.22
	Copper	RS2	3	0.65	1.24	0.18
		SS3	6	2.50	3.58	0.33
	Lead	RS2	3	0.10	2.15	0.04
		SS3	6	1.90	3.49	0.25
	Mercury	RS2	3	0.01	0.02	0.00
		SS3	6	0.02	0.03	0.00
	Molybdenum	RS2	3	0.10	0.31	0.03
		SS3	6	0.33	0.60	0.04
	Nickel	RS2	3	0.80	3.38	0.25
		SS3	6	4.40	7.26	0.51
	Selenium	RS2	3	0.00	0.08	0.00

		SS3	6	0.27	0.29	0.04
Alkylated PAHs (ng/g)	Total APAHs	RS2	3	228.60	216.61	72.41
		SS3	6	2697.47	1593.43	345.83
	C1 Chrysene	RS2	3	8.98	7.29	2.93
		SS3	6	324.72	138.32	39.76
	C1 Dibenzothiophene	RS2	3	2.50	0.98	0.80
		SS3	6	40.32	31.21	5.62
	C1 Fluorene	RS2	3	0.84	0.35	0.25
		SS3	6	8.54	4.78	1.03
	C2 Chrysene	RS2	3	29.68	23.17	9.58
		SS3	6	999.88	555.93	131.04
	C2 Dibenzothiophene	RS2	3	8.89	9.77	2.86
		SS3	6	44.01	46.70	6.56
	C2 Fluorene	RS2	3	16.75	8.90	5.31
		SS3	6	25.47	25.96	3.66
	C2 Naphthalene	RS2	3	3.26	12.01	1.03
		SS3	6	258.52	60.04	31.28
	C2 Phenanthrene	RS2	3	11.61	8.53	3.80
		SS3	6	178.66	73.65	21.63
	C3 Chrysene	RS2	3	2.24	4.85	0.61
		SS3	6	102.27	34.21	12.14

	C3 Dibenzothiophene	RS2	3	4.07	6.01	1.14
		SS3	6	31.89	31.78	4.85
	C3 Fluorene	RS2	3	32.02	16.66	10.13
		SS3	6	72.71	64.95	10.40
	C3 Naphthalene	RS2	3	6.88	7.83	2.18
		SS3	6	122.87	36.13	14.54
	C3 Phenanthrene	RS2	3	12.94	12.84	4.26
		SS3	6	196.36	87.35	24.29
	C4 Chrysene	RS2	3	1.45	4.83	0.37
		SS3	6	49.88	16.64	5.68
	C4 Dibenzothiophene	RS2	3	46.09	43.40	15.35
		SS3	6	240.33	219.22	33.26
	C4 Fluorene	RS2	3	17.60	10.00	5.57
		SS3	6	31.20	34.07	4.18
	C4 Naphthalene (Butyl)	RS2	3	7.48	6.86	2.37
		SS3	6	141.42	37.22	16.71
	C4 Phenanthrene	RS2	3	13.92	19.84	4.60
		SS3	6	137.03	66.68	18.61
	Dibenzothiophene	RS2	3	0.17	0.16	0.06
		SS3	6	8.07	7.99	1.05
	Retene	RS2	3	14.29	12.34	4.62

		SS3	6	44.93	20.60	5.42
Parent PAHs (ng/g)	Total PAHs	RS2	3	119.15	28.88	30.98
		SS3	6	65.40	124.87	8.62
	Acenaphthene	RS2	3	1.76	0.86	0.42
		SS3	6	0.80	1.23	0.09
	Acenaphthylene	RS2	3	2.35	1.13	0.56
		SS3	6	1.17	1.62	0.15
	Anthracene	RS2	3	4.82	1.65	1.20
		SS3	6	3.51	5.20	0.42
	Benz[a]anthracene	RS2	3	15.31	3.68	3.93
		SS3	6	8.95	17.16	1.26
	Benzo[a]pyrene	RS2	3	27.24	4.88	7.17
		SS3	6	14.44	21.13	2.14
	Benzo[b]fluoranthene	RS2	3	9.89	2.00	2.59
		SS3	6	6.59	11.93	0.79
	Benzo[g,h,i]perylene	RS2	3	15.05	2.74	3.95
		SS3	6	7.94	16.19	1.22
	Benzo[k]fluoranthene	RS2	3	4.16	0.89	1.07
		SS3	6	3.76	5.28	0.55
	Dibenzo[a,h]anthracene	RS2	3	6.07	1.39	1.52
		SS3	6	3.13	6.90	0.47

	Fluoranthene	RS2	3	8.27	2.80	2.07
		SS3	6	5.09	8.90	0.51
	Indeno[1,2,3-c,d]pyrene	RS2	3	5.62	1.11	1.47
		SS3	6	2.49	5.84	0.34
	Pyrene	RS2	3	21.31	5.74	5.38
		SS3	6	14.81	23.48	1.66
Soil Properties	CEC (cmol+/kg)	RS2	3	9.52	6.80	3.15
		SS3	6	27.80	40.65	3.37
	EC (mS/cm)	RS2	3	0.03	0.06	0.01
		SS3	6	0.08	0.14	0.01
	OM (% dry)	RS2	3	3.90	3.41	1.24
		SS3	6	15.80	23.78	2.31
	Gravel (%)	RS2	3	0.00	0.00	0.00
		SS3	6	1.30	0.51	0.16
	Sand (%)	RS2	3	8.40	90.38	2.75
		SS3	6	36.40	49.21	5.01
	Silt (%)	RS2	3	2.10	5.15	0.69
		SS3	6	19.00	27.03	2.24
	Clay (%)	RS2	3	7.10	4.42	2.15
		SS3	6	21.50	23.75	2.99
	Phosphorus (mg/L soil dry)	RS2	3	9.00	18.83	2.25

		SS3	6	3.70	7.65	0.41
	Potassium (mg/L soil dry)	RS2	3	7.00	38.33	1.67
		SS3	6	23.00	69.71	3.10
	pH	RS2	3	0.50	5.28	0.13
		SS3	6	0.40	4.85	0.06
	Moisture (% dry)	RS2	3	4.86	11.30	1.21
		SS3	6	35.81	51.14	5.12
	Nitrogen (% dry)	RS2	3	0.18	0.10	0.06
		SS3	6	0.19	0.39	0.03

N = Sample Size. Variables abbreviations: Arsenic = As; Cadmium = Cd; Chromium = Cr; Cobalt = Co; Copper = Cu; Lead = Pb; Mercury = Total Hg; Molybdenum = Mo; Nickel = Ni; Selenium = Se; Zinc = Zn; CEC = Cation Exchange Capacity; EC = Electrical Conductivity; OM = Organic Matter; Phosphorus = Total P; Potassium = Total K; Nitrogen = Total N

For the blueberry fruits, a total of 13 samples (without replicates) were analyzed: 6 from SS3 and 7 from RS2 (Table 2b). Similar to their respective soils, fruit samples from SS3 exhibited higher mean concentrations compared to those from RS2. Elements such as Pb, Cd, Hg, and As from both sites showed consistent and negligible concentrations in blueberry fruit samples when considering two decimal places. The concentration range varied across the sites and variables. Antioxidants, particularly Vitamin C in samples from both sites, and APAHs (with a range of 47.92 ng/g for total APAHs in SS3 samples) displayed the largest ranges. In contrast, primarily TEs and some hydrocarbons, such as total Hg, indicated no variability between samples from these sites. Compared to the corresponding soil, blueberry fruits generally exhibited lower mean concentrations of the same chemicals. For example, the mean concentrations of total APAHs in blueberry soil and fruit samples from RS2 were 224 ng/g and 9.81 ng/g, respectively.

When compared with pin cherry fruit samples, blueberry fruits from RS2 generally have higher concentrations for the majority of chemicals and some fruit quality variables. However, pin cherry fruits from RS1 dominate in specific chemicals, mainly TEs (Zn, Se, Mo, Mg, and Cu) and several fruit quality variables, except for TAA and TAnC. Among the reclaimed sites, fruits from SS1 mostly exhibited higher mean concentrations of chemicals compared to pin cherries from SS2 and blueberries from SS3, with a few exceptions including fruit quality variables. SS1 samples had higher concentrations in TAC, TAnC, Vitamin C, and pH, while SS2 samples were superior in TAA, TPC, and Water Content concentrations.

Table 2b: Descriptive statistics for trace elements (mg/kg dry weight), and polycyclic aromatic hydrocarbons (parent and alkylated; ng/g), and fruit quality variables of blueberry fruit samples from Oil Sands Reclaimed (SS3) and Natural (RS2) sites in Fort McMurray, Alberta.

Groups (Units)	Variables	Sites	N	Concentration Range	Mean Concentration	Standard error of the mean
Trace Elements (mg/Kg)	Arsenic	RS2	7	0.01	0.00	0.00
		SS3	6	0.01	0.01	0.00
	Boron	RS2	7	1.00	1.52	0.11
		SS3	6	1.37	1.76	0.23
	Cadmium	RS2	7	0.00	0.00	0.00
		SS3	6	0.00	0.00	0.00
	Chromium	RS2	7	0.03	0.02	0.00
		SS3	6	0.17	0.04	0.03
	Cobalt	RS2	7	0.01	0.01	0.00
		SS3	6	0.01	0.01	0.00
	Copper	RS2	7	0.34	0.71	0.04
		SS3	6	0.55	0.80	0.08
	Iron	RS2	7	21.60	11.19	2.22
		SS3	6	6.70	7.97	0.94
	Lead	RS2	7	0.00	0.00	0.00
		SS3	6	0.01	0.01	0.00
	Magnesium	RS2	7	39.00	81.67	4.12
		SS3	6	21.00	101.17	3.25
	Mercury	RS2	7	0.00	0.00	0.00

		SS3	6	0.00	0.00	0.00
	Molybdenum	RS2	7	0.09	0.04	0.01
		SS3	6	0.03	0.01	0.01
	Nickel	RS2	7	0.11	0.09	0.01
		SS3	6	0.09	0.12	0.01
	Zinc	RS2	7	1.49	1.68	0.15
		SS3	6	2.40	2.17	0.34
Alkylated PAHs (ng/g)	Total APAHs	RS2	7	25.59	9.74	3.42
		SS3	6	47.92	19.28	7.81
	C1 Chrysene	RS2	7	0.75	0.27	0.08
		SS3	6	0.83	0.41	0.13
	C2 Chrysene	RS2	7	1.71	0.66	0.20
		SS3	6	1.23	1.27	0.20
	C2 Naphthalene	RS2	7	15.34	3.22	1.75
		SS3	6	2.63	0.85	0.39
	C2 Phenanthrene	RS2	7	0.93	0.69	0.11
		SS3	6	5.06	1.72	0.88
	C3 Chrysene	RS2	7	0.24	0.07	0.03
		SS3	6	0.14	0.04	0.02
	C3 Naphthalene	RS2	7	0.58	0.10	0.06
		SS3	6	0.94	0.32	0.17
	C3 Phenanthrene	RS2	7	1.70	0.80	0.21

		SS3	6	7.46	2.73	1.08
	C4 Chrysene	RS2	7	0.00	0.10	0.00
		SS3	6	0.01	0.00	0.00
	C4 Naphthalene (Butyl)	RS2	7	0.14	0.04	0.02
		SS3	6	0.76	0.17	0.12
	C4 Phenanthrene	RS2	7	1.04	0.40	0.13
		SS3	6	2.18	0.54	0.36
	C1 Dibenzothiophene	RS2	7	0.25	0.07	0.03
		SS3	6	0.90	0.23	0.14
	C1 Fluorene	RS2	7	0.43	0.09	0.05
		SS3	6	1.51	0.27	0.25
	C2 Dibenzothiophene	RS2	7	1.42	0.38	0.15
		SS3	6	3.21	0.80	0.51
	C2 Fluorene	RS2	7	0.53	0.16	0.06
		SS3	6	1.54	0.33	0.25
	C3 Dibenzothiophene	RS2	7	1.61	0.53	0.17
		SS3	6	3.49	0.82	0.57
	C3 Fluorene	RS2	7	1.02	0.21	0.11
		SS3	6	2.39	0.53	0.39
	C4 Dibenzothiophene	RS2	7	6.70	1.81	0.78
		SS3	6	11.88	2.31	1.92
	C4 Fluorene	RS2	7	0.32	0.18	0.03

		SS3	6	0.94	0.71	0.12
	Dibenzothiophene	RS2	7	0.06	0.04	0.01
		SS3	6	0.34	0.09	0.05
	Retene	RS2	7	0.28	0.21	0.03
		SS3	6	0.35	0.17	0.05
Parent PAHs (ng/g)	Total PAHs	RS2	7	0.20	0.60	0.02
		SS3	6	13.39	2.84	2.21
	Acenaphthene	RS2	7	0.00	0.07	0.00
		SS3	6	0.54	0.16	0.09
	Acenaphthylene	RS2	7	0.07	0.06	0.01
		SS3	6	0.52	0.15	0.09
	Anthracene	RS2	7	0.00	0.04	0.00
		SS3	6	0.30	0.08	0.05
	Benz[a]anthracene	RS2	7	0.05	0.04	0.01
		SS3	6	1.29	0.26	0.21
	Benzo[a]pyrene	RS2	7	0.04	0.05	0.00
		SS3	6	1.46	0.29	0.24
	Benzo[b]fluoranthene	RS2	7	0.02	0.03	0.00
		SS3	6	1.59	0.28	0.26
	Benzo[g,h,i]perylene	RS2	7	0.03	0.03	0.00
		SS3	6	1.30	0.24	0.21
	Benzo[k]fluoranthene	RS2	7	0.04	0.04	0.00

		SS3	6	1.52	0.29	0.25
	Dibenzo[a,h]anthracene	RS2	7	0.00	0.05	0.00
		SS3	6	1.24	0.25	0.21
	Fluoranthene	RS2	7	0.05	0.04	0.01
		SS3	6	1.15	0.23	0.19
	Indeno[1,2,3-c,d]pyrene	RS2	7	0.10	0.10	0.01
		SS3	6	1.33	0.33	0.22
	Pyrene	RS2	7	0.08	0.05	0.01
		SS3	6	1.24	0.27	0.20
Fruit Quality Variables	TAnC (cyanidin-3-glucoside equivalents, mg/L)	RS2	7	34.80	16.09	3.49
		SS3	6	16.27	7.58	2.39
	TAA (µmol Trolox equivalency/g)	RS2	7	30.56	49.56	3.68
		SS3	6	34.88	39.67	5.87
	TAC (mg AA/g)	RS2	7	2.78	7.03	0.30
		SS3	6	6.92	6.15	1.04
	TPC (mg TAE/g)	RS2	7	5.12	11.61	0.47
		SS3	6	3.06	9.35	0.50
	Vitamin C (mg per 100 g of fresh weight of the fruit)	RS2	7	73.05	119.75	8.46
		SS3	6	62.59	116.70	11.64
	pH	RS2	7	0.25	3.37	0.03
		SS3	6	0.12	3.35	0.02
	Water Content (g/g)	RS2	7	0.04	0.37	0.00

		SS3	6	0.06	0.36	0.01

N = Sample Size. Variables abbreviations: Arsenic = As; Boron = B; Cadmium = Cd; Chromium = Cr; Cobalt = Co; Copper = Cu; Iron = Fe; Magnesium = Mg; Lead = Pb; Mercury = Total Hg; Molybdenum = Mo; Nickel = Ni; Selenium = Se; Zinc = Zn; TAnC = Toal Anthocyanin Content; TAA = Total Antioxidant Activity; TAC = Total Antioxidant Capacity; TPC = Total Phenolic Content.

The levels of tested chemicals in both fruit and soil samples were compared against guideline limits established by regulatory bodies such as World Health Organization/Food and Agriculture Organization (WHO/FAO), European Commission (EU Commission), Canadian Council of Ministers of the Environment Soil Quality Guidelines for the protection of Environmental and Human Health (CCME SQGE), and the Alberta Tier 1 Soil Remediation Guidelines 2022 (Refer to the appendix Table 12 and 13 for specific limits on different chemicals). As shown in Figure 5, only the mean concentration levels (mg/Kg) of Cu and Fe in the tested fruit samples exceeded their respective guideline limits. These limits represent the maximum concentration levels for various chemicals deemed toxic compounds in food/plants, aligning with the guidelines set forth by FAO/WHO (also referred to as Maximum Allowable Limits or MAL). The established MAL for Cu and Fe in edible vegetable oils is 0.10 mg/Kg and 2.50 mg/Kg, respectively. Importantly, these limits have not yet been established for berries and other small fruits. Given that the majority of established limits for these two Trace Elements (TEs) are intended for meat products, vegetable oils were used as a suitable proxy to evaluate safety limits in berries. The arithmetic mean concentrations (mg/Kg) of Cu and Fe in fruit samples from the study sites (SS1, SS2, SS3, RS1, and RS2) in 2022, presented in Figure 5 are as follows: pin cherry fruit samples from SS1, SS2, and RS1 exhibited mean Cu and Fe concentrations of 1.36 and 5.88 mg/Kg, 1.90 and 7.26 mg/Kg, and 1.37 and 7.22 mg/Kg, respectively. Blueberry fruit samples from SS3 and RS2 demonstrated mean Cu and Fe concentrations of 0.78 and 7.81 mg/Kg, and 0.70 and 11.53 mg/Kg, respectively.

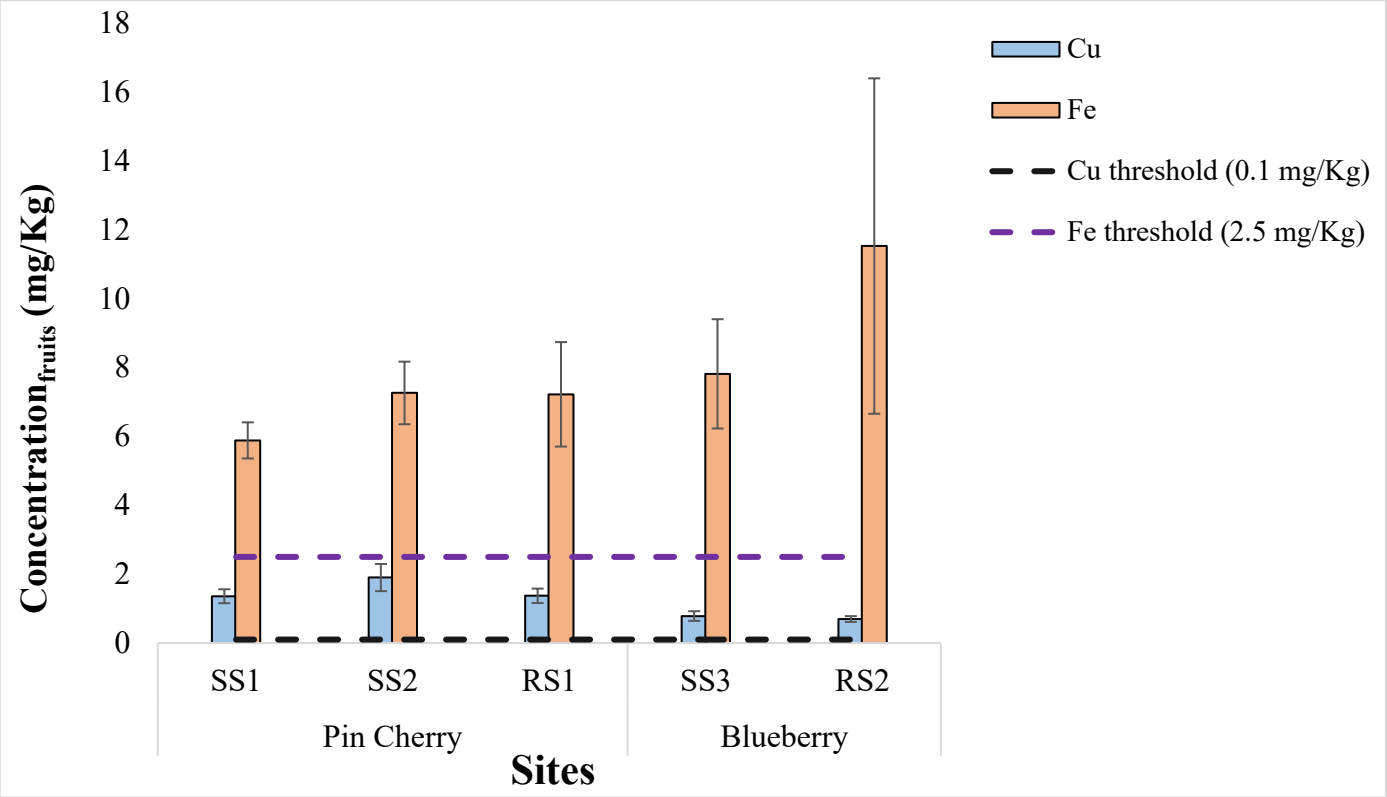

Figure 5: Arithmetic mean concentration (mg/Kg) of copper (Cu; blue bars) and iron (Fe; orange bars) in fruit samples from pin cherry (SS1, SS2, RS1) and blueberry (SS3, RS2) collected sites in Fort McMurray, Alberta 2022, exceeding the maximum allowed limits (MAL) for copper (black dashed lines) and iron (purple dashed lines) in food (mg/Kg) guidelines based on WHO/FAO. Error bars represent margin of error at the 95% confidence interval. Sample sizes for SS1, SS2, SS3, RS1, and RS2 are 10, 10, 6, 4, and 7, respectively. SS1 = Reclaimed Site 1, SS2 = Reclaimed Site 2, SS3 = Reclaimed Site 3, RS1 = Natural Site 1, RS2 = Natural Site 2.

B. Relationship of TE and PAH concentrations between soil and berries

Among the analyzed chemicals, including TEs and hydrocarbons, almost none showed significant correlations between soil and fruit samples for the same chemical within each berry type (blueberry and pin cherry; see Table 3a and 3b, respectively). The exception was molybdenum (Mo) in pin cherries, but this association was relatively weak (R = -0.46).

Table 3a: Pearson Correlation (R) analysis between the mean concentration of Trace Elements (TEs; mg/Kg) and Total Parent and Alkylated-PAHs (PAHs and APAHs) standardized against total organic carbon (ng/g_{OC}) in blueberry fruits (top) and the mean concentration of same chemicals in the corresponding soil samples (left) from Fort McMurray, Alberta sites (SS3, RS2). Significant correlations are bolded ($p \leq 0.05$). Significance levels: ** = $p \leq 0.01$, * = $p \leq 0.05$. N = sample Size (includes duplicates).

	Groups (Units)	Chemicals	blueberry Fruits (N = 15)														
			Trace Elements (mg/Kg)													PAHs (ng/g)	
			As	B	Co	Pb	Mg	Hg	Ni	Cd	Cr	Cu	Fe	Mo	Zn	Total APAHs	Total. PAHs
blueberry Soil (N = 15)	TEs (mg/Kg)	As	-0.05	0.13	0.18	0.21	**0.66 ** **	0.41	0.46	0.23	0.24	0.27	-0.22	-0.26	0.39	0.18	0.02
		Cd	0.04	-0.04	0.09	0.24	0.50	0.31	0.35	0.08	0.26	0.25	-0.04	-0.13	0.28	0.20	-0.09
		Cr	0.03	0.16	0.23	0.34	**0.62***	0.40	0.44	0.28	0.32	0.26	-0.16	-0.29	0.39	0.30	0.02
		Co	-0.01	0.10	0.16	0.30	**0.62***	0.45	0.47	0.23	0.33	0.29	-0.15	-0.24	0.39	0.21	-0.06
		Cu	0.02	0.01	0.14	0.25	**0.55***	0.30	0.35	0.13	0.23	0.21	-0.09	-0.17	0.28	0.26	-0.04
		Pb	0.00	0.08	0.19	0.27	**0.53***	0.30	0.36	0.16	0.21	0.18	-0.14	-0.23	0.30	0.35	-0.05
		Hg	-0.04	-0.22	-0.04	0.13	0.19	0.13	0.13	-0.17	0.05	-0.01	0.08	0.09	0.03	0.21	-0.25
		Mo	0.07	0.07	0.13	0.39	**0.58***	0.46	0.45	0.24	0.42	0.31	-0.04	-0.20	0.36	0.15	-0.05
		Ni	0.07	0.21	0.27	0.35	**0.64***	0.38	0.42	0.32	0.34	0.28	-0.17	-0.34	0.41	0.28	-0.01
		Se	0.06	0.17	0.26	0.29	**0.58***	0.27	0.34	0.26	0.25	0.21	-0.16	-0.31	0.34	0.31	0.04
		Zn	-0.04	0.39	0.24	0.12	0.21	0.22	0.21	0.32	0.15	0.19	-0.27	-0.36	0.34	-0.05	-0.28
	Hydrocarbon (ng/g_{OC})	Total APAHs	0.48	**0.71 ** **	**0.65 ** **	0.38	0.34	-0.13	-0.01	**0.62***	0.32	0.34	-0.15	**-0.59***	0.43	0.31	0.18
		Total PAHs	0.10	**0.54***	0.42	-0.05	0.40	-0.03	0.14	0.46	0.06	0.33	-0.41	**-0.54***	0.44	0.02	0.14

Table 3b: Pearson Correlation (R) analysis between the mean concentration of Trace Elements (TEs, mg/Kg) and Total Parent and Alkylated-PAHs (PAHs and APAHs) standardized against total organic carbon (ng/g_{OC}) in pin cherry fruits (top) and the mean concentration of same chemicals in the corresponding soil samples (left) from Fort McMurray, Alberta sites (SS1, SS2, RS1). Significant correlations are bolded ($p \leq 0.05$). Significance levels: ** = $p \leq 0.01$, * = $p \leq 0.05$. N = sample Size (includes duplicates).

	Groups (Units)	Chemicals	pin cherry fruits (N = 26)													
			Trace Elements (mg/Kg)												PAHs (ng/g)	
			As	B	Co	Mg	Hg	Ni	Cr	Cu	Fe	Mo	Zn	Se	Total APAHs	Total PAHs
pin cherry Soil (N = 26)	TEs (mg/Kg)	As	0.33	**0.68****	**0.44***	0.34	**-0.46***	0.21	**-0.50****	-0.04	-0.18	**-0.46****	0.25	0.24	**0.44***	0.30
		Cd	0.04	0.11	0.07	-0.08	0.06	0.03	0.06	0.29	0.17	-0.03	-0.02	-0.29	-0.26	0.16
		Cr	0.35	0.25	0.28	-0.08	-0.09	0.28	-0.28	-0.06	0.12	-0.19	-0.08	-0.02	0.02	0.21
		Co	0.19	0.37	0.22	-0.08	-0.06	0.10	-0.34	0.11	0.13	-0.07	-0.08	0.07	0.08	0.29
		Cu	0.30	**0.53****	0.18	0.16	-0.12	-0.03	-0.17	0.28	0.22	-0.16	0.08	0.04	-0.06	0.26
		Pb	0.19	0.35	0.19	-0.04	-0.08	0.12	-0.31	0.07	0.11	-0.14	-0.01	-0.07	-0.04	0.18
		Hg	0.05	**0.58****	0.37	0.35	-0.27	0.30	0.19	0.09	-0.18	-0.37	0.31	-0.06	-0.11	0.28
		Mo	0.15	**0.40***	0.06	0.35	-0.12	0.08	0.22	0.17	0.10	**-0.46***	0.33	-0.06	0.11	0.16
		Ni	0.32	**0.48***	0.27	0.08	-0.16	0.14	-0.24	0.08	0.09	-0.23	0.01	0.03	0.03	0.29
		Se	0.23	0.30	0.28	-0.07	-0.08	0.14	-0.30	0.09	0.08	-0.03	-0.06	-0.07	-0.11	0.14
		Zn	-0.05	0.02	0.09	-0.27	0.04	-0.05	-0.21	0.02	0.02	0.11	-0.25	-0.16	-0.28	-0.14
	Hydrocarbons (ng/g_{OC})	Total APAHs	0.22	**0.44***	0.21	**0.53****	-0.22	-0.38	-0.13	0.28	-0.04	-0.08	0.27	**0.41***	0.18	0.16
		Total PAHs	0.08	0.28	0.00	0.11	0.11	**-0.40***	-0.05	0.29	0.20	0.32	-0.01	**0.59****	0.09	0.23

We also investigated the correlations observed among different chemicals within the soil and fruit samples for each respective berry type (Tables 4-6). The correlation analyses were undertaken to identify potential patterns linking chemicals in the soil with those in the fruits. Such patterns offer insights into possible factors affecting the uptake of chemicals from soil to berries. In this study, only correlations that are both strong and statistically significant ($R > \pm 0.8$; $p < 0.05$) are elaborated upon in the findings.

Table 4 presents the correlation (R) between the mean concentration (mg/Kg) of various TEs in blueberry soil samples and the mean concentration of different chemicals in respective blueberry fruit samples. Specific APAH, namely APAH14, in the blueberry fruit samples, demonstrated strong- negative linear relationships with concentrations of several TEs (specifically, As, Cr, Co, and Cu) in the soil ($p < 0.01$). For instance, 76% ($R^2 = 0.76$) of the variance in APAH14 concentrations in the blueberry fruit samples was attributable to the combined concentrations of these TEs in the corresponding soil samples (Figure 6).

Table 4: Pearson Correlation (R) analysis between the mean concentration of Alkylated-PAH14 (C4 Chrysene) in blueberry fruit (ng/g) and the concentration of Trace Elements (TEs) in the corresponding soil samples (mg/Kg dry weight) from Fort McMurray, Alberta sites (SS3, RS2). Strong correlations are bolded ($R \geq \pm 0.8$). Significance levels: ** = $p \leq 0.01$, * = $p \leq 0.05$.

TEs in blueberry Soil Samples (mg/Kg)	Chemicals in blueberry Fruit Samples
	APAH14 (ng/g)
Arsenic (As)	**-0.87****
Chromium (Cr)	**-0.81****
Cobalt (Co)	**-0.85****
Copper (Cu)	**-0.81****

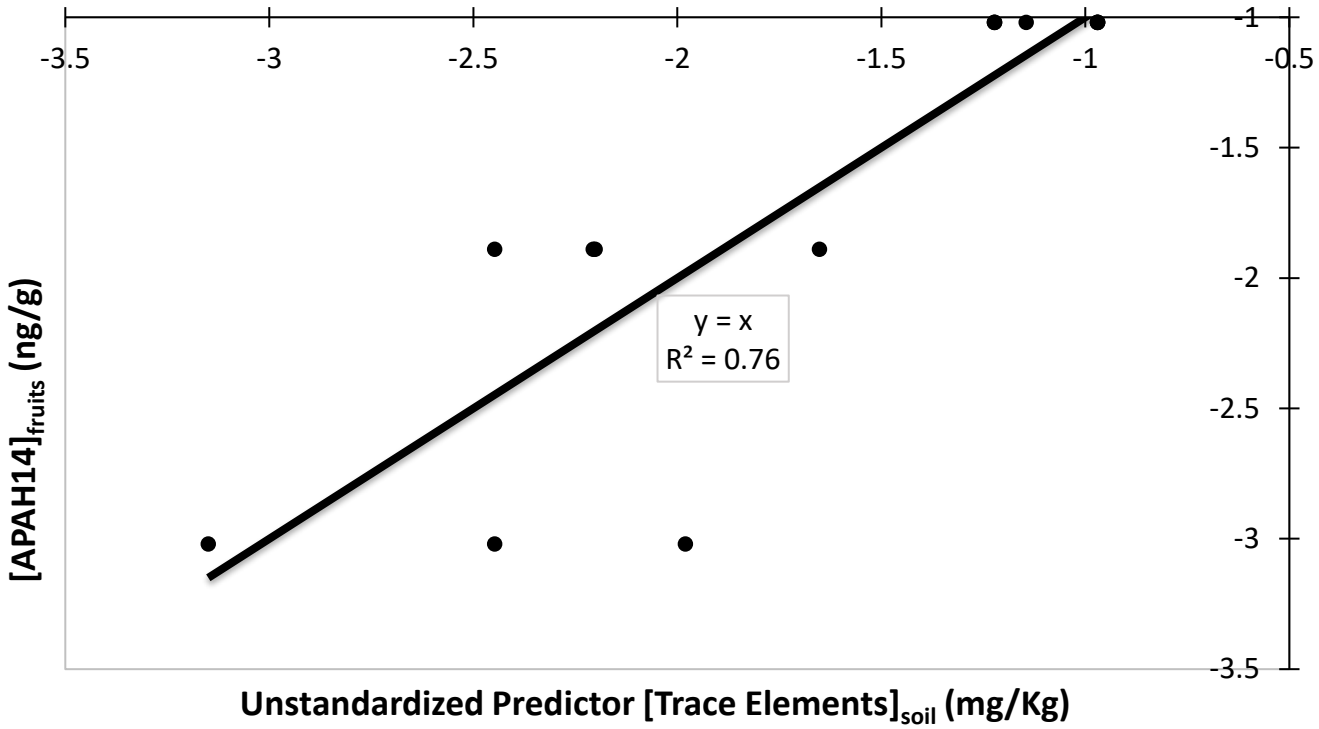

Figure 6: Scatter plot illustrating the multiple linear regression of the mean concentration of Alkylated-PAH14 (C4 Chrysene; ng/g) in blueberry fruit samples against the unstandardized predictor values of Trace Elements (mg/Kg) in soil samples from studied sites (SS3, RS2). These variables are strongly and significantly correlated, as shown in Table 4 ($R \geq \pm 0.8$; $p \leq 0.05$). The plot includes the equation of the line ($y = mx+b$), r^2, and the regression line. Dependent variable and independent variable is transformed (Log10).

Table 5 outlines the correlations between the average concentrations of TOC-standardized APAHs (both total and individual compounds) in soil samples (ng/g_{OC}) and the respective mean concentrations of APAHs in blueberry fruit samples (ng/g) collected from the study sites in 2022. Notably, a strong linear relationship ($R > 0.8$; $p < 0.01$) exists between specific APAH concentrations in the soil and their counterparts in the fruit samples, but between different APAH compound, particularly APAH14 in the fruits. Interestingly, 77% of the variability in the APAH14 concentrations in the blueberry fruit samples is explained by the combined concentrations of individual APAH monomers, namely APAH19 and APAH20, in the corresponding soil samples (as depicted in Figure 7).

Table 5: Pearson Correlation (R) analysis between the mean concentration of Alkylated-PAH14 (C4 Chrysene) in blueberry fruit (ng/g) and the concentration of total organic carbon (TOC) standardized Alkylated PAH19 (C4 Phenanthrene; ng/g_{OC}) and APAH20 (Retene; ng/g_{OC}) in the corresponding soil samples from Fort McMurray, Alberta sites (SS3, RS2). Strong correlations are bolded (R ≥ ± 0.8). Significance levels: ** = p ≤ 0.01, * = p ≤ 0.05.

TOC standardized APAHs in blueberry Soil Samples (ng/g_{OC})	Chemicals in blueberry Fruit Samples
	APAH14 (ng/g)
APAH19	**0.82****
APAH20	**0.86****

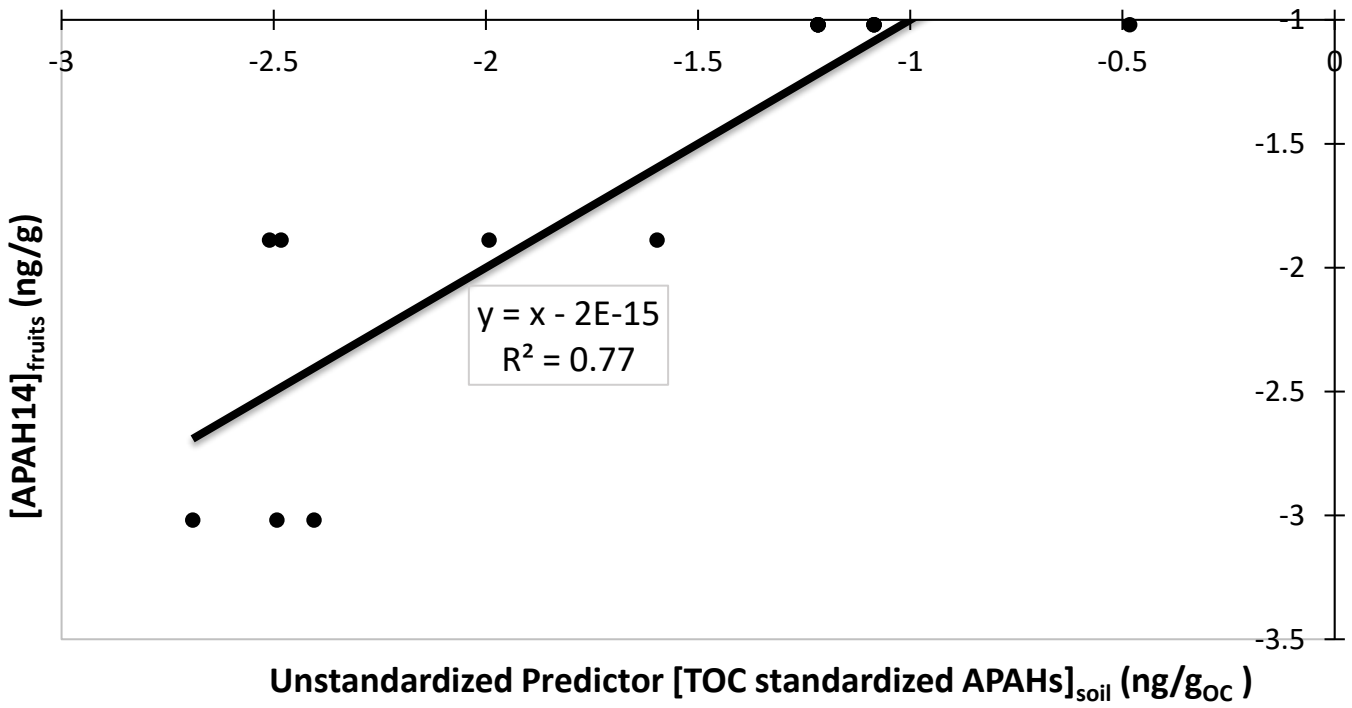

Figure 7: Scatter plots illustrating the relationship between the mean concentration of Alkylated-PAH14 (C4 Chrysene; ng/g) in blueberry fruit samples against the unstandardized predictor values of total organic carbon (TOC) standardized Alkylated PAHs (ng/g_{OC}) in soil samples from studied sites (SS3, RS2). These samples were taken from blueberry collection sites (SS3, RS2). The plots include the equation of the line (y = mx+b), r^2, and the regression line. The displayed relationships were significantly strong, as noted in Table 5 (R ≥ ± 0.8; p ≤ 0.05). Dependent variable is transformed (Log10).

In pin cherry samples collected from Fort McMurray sites (SS1, SS2, and RS1), the mean concentration of TOC-standardized APAHs, namely APAH3, 6, and 7 in the soil (ng/g_{OC}) and the mean concentration of total APAH9 (ng/g) in the fruit samples have a strong linear association ($R > 0.8$; $p < 0.01$; Table 6). This indicates that as the concentration of different TOC-standardized individual APAH monomers in the soil increases, the concentration of APAH9 in the pin cherry fruits also tends to rise. Nevertheless, the detected concentration of APAH9 in these fruits from only RS1 is negligible, registering up to only two decimal places. However, given its statistical significance, this observed relationship is likely evident in the two sampled reclaimed sites (SS1 and SS2). Furthermore, 70% of the variation in APAH9 in the sampled pin cherry fruits can be attributed to the variations in the combined TOC-standardized APAH concentrations in the soil (Figure 8).

Table 6: Pearson Correlation (R) analysis between the mean concentration of Alkylated-PAH9 (C3 Chrysene; ng/g) in pin cherry fruit and the concentration of total organic carbon (TOC) standardized Alkylated PAH3 (C2 Dibenzothiophene; ng/g_{OC}), APAH6 (C3 Fluorene; ng/g_{OC}), and APAH7 (C4 Dibenzothiophene; ng/g_{OC}) in the corresponding soil samples from Fort McMurray, Alberta sites (SS1, SS2, RS1). Strong correlations are bolded (R ≥ ± 0.8). Significance levels: ** = p ≤ 0.01, * = p ≤ 0.05.

TOC standardized APAHs in blueberry Soil Samples (ng/g_{OC})	Chemicals in pin cherry Fruit Samples
	APAH9 (ng/g)
APAH3	**0.83****
APAH6	**0.83****
APAH7	**0.82****

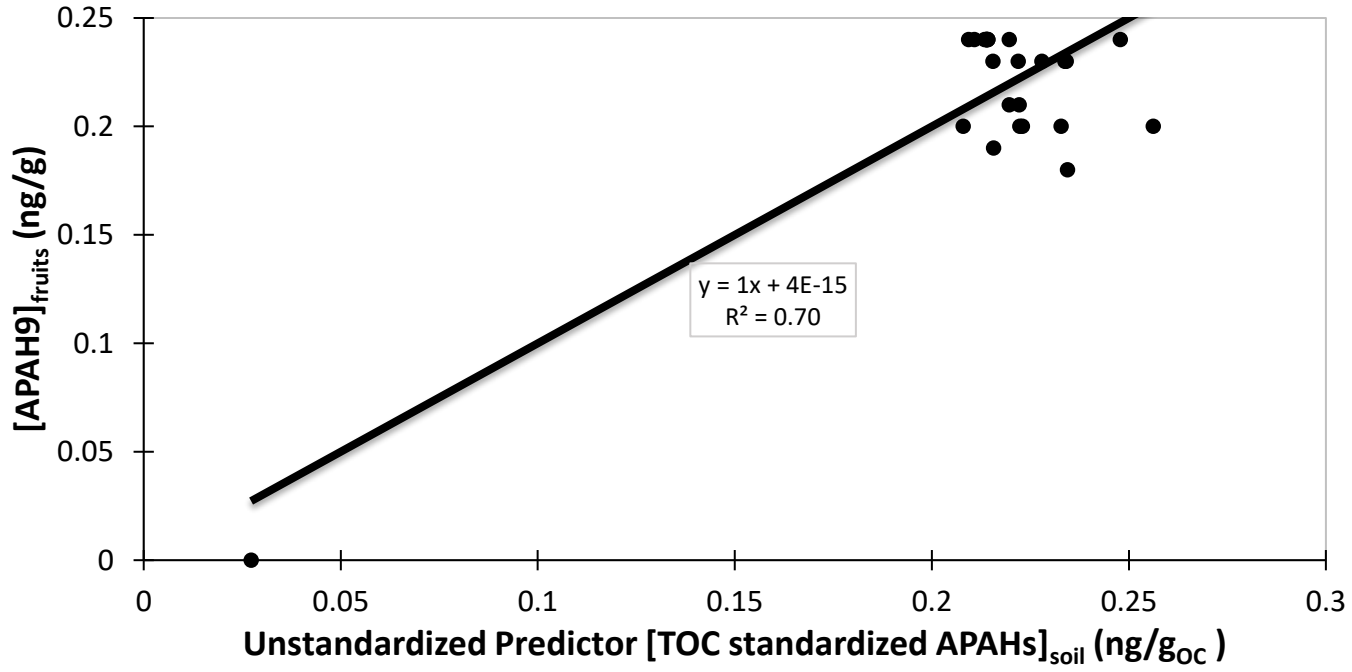

Figure 8: Scatter plot illustrating the relationship between the mean concentration of standardized Alkylated-PAH9 (C3 Chrysene; ng/g) in sampled pin cherry fruits and the unstandardized predictor values of total organic carbon (TOC) standardized Alkylated PAHs (ng/g_{OC}) in the corresponding pin cherry soil samples from the studied sites (SS1, SS2, RS1). These variables show a strong and significant correlation (R = 0.80; p ≤ 0.05), as indicated by Table 6. Each plot includes R, the equation of the line (y = mx+b), r^2, and the regression line. Dependent variable and independent variable is transformed (Log10).

C. Relationship between concentration of environmental variables in soil and in berries

PCA was employed to investigate the relationships between concentrations of environmental variables in soil and berries. In each analysis, we focused on the top four Principal Components identified (PC1-4) because they collectively account for the majority of the variance observed in the sample data. Variables with high loadings (absolute value of loadings ≥ 0.7) in PC1 are the primary determinants of the variance in these samples (See appendix tables 6-11 for the factor loadings). Conversely, variables with moderate loadings (absolute value of loadings ≥ 0.3) exert a less pronounced influence on the sample variance. In the biplots, red dotted vector lines indicate environmental variables; longer lines (higher the loadings) suggest stronger correlations with their respective PCs. Vectors pointing towards a PC's positive direction signify positive correlations and opposite is negative correlation. With ascending component numbers, the explained variance diminishes. Consequently, variables in PC1 and 2 exert a dominant influence on the overall sample variance than those in PC 3 and 4. The detailed PCA findings are described below.

Figure 9 presents the PCA biplot of pin cherry soil samples from the study sites: SS1, SS2, and RS1. In Figure 9A, the combined contributions of PC1 and PC2 account for 56.0 % of the total variance in the environmental variables of these samples, capturing a substantial portion of the dataset's variability. In contrast, Figure 9B illustrates that PC3 and PC4 together represent a lesser, yet still significant, 15.9% of the variance.

PC1 explains 31.73% of the total variance and the variables included soil TEs (*i.e.,* Cd, Cr, Co, Cu, Pb, Ni, Se), and properties (*i.e.,* CEC, EC, OM, Silt, Clay, total K, and total N). PC2 accounts for 24.23% of the variance, and the influencers include hydrocarbons such as APAHs (*i.e.,* APAH-1, 9, 10, 11, and total), and PAHs (*i.e.,* PAH-4, 5, 7, 9, and total). PC3 and PC4 representing 8.31% and 7.60%, respectively of the total variance presented less patterns, but showed more specific associations, where PC3 and PC4 primarily correlated with APAH12 and APAH4, respectively.

In the biplot (Figure 9A and B), most samples from SS2 (except S2, 6, and 7) align positively with the variables represented by PC1, clustering in the positive direction of PC1. Conversely, SS1 (except A2 and 9) and RS1 samples exhibit the opposite characteristics, clustering towards the negative direction of PC1. Almost all SS2 samples (except S10) specifically are positively characterized by the environmental variables associated with PC2. As for the variables tied to PC3 and PC4, SS1 and RS1 samples distinctly align positively with those linked to PC3 and a clear clustering pattern of SS1 samples aligned positively with PC4.

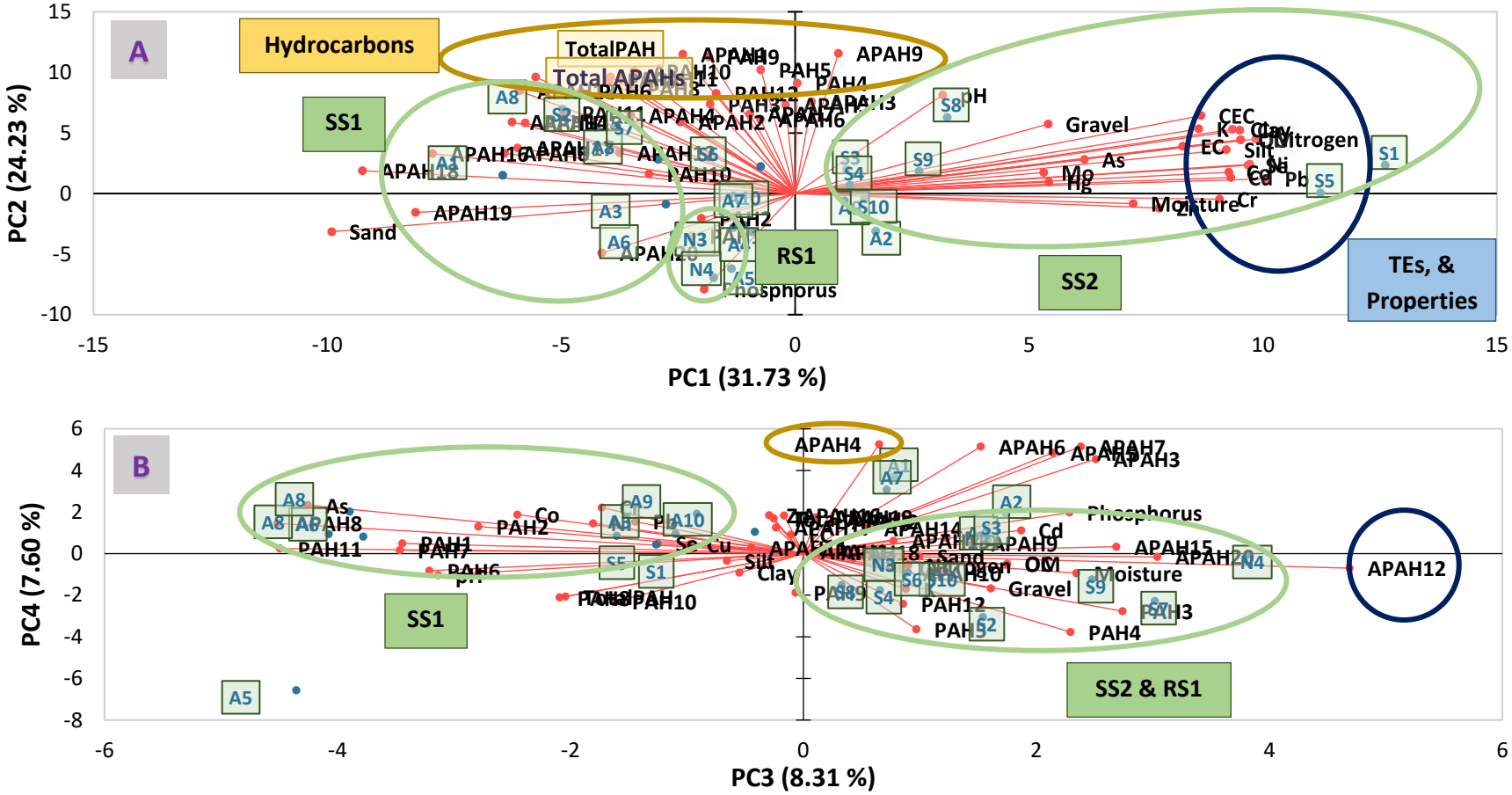

Figure 9: Principal components analysis (PCA) biplots for environmental variables analyzed in pin cherry collected Soil samples from Fort McMurray, Alberta, 2022 for (A) PC1-2, and (B) PC3-4. Blue dotted Green squares Represent Individual Soil Samples (n = 26). Red lined Black Vectors Indicate individual environmental variables. APAHs (total organic carbon or TOC standardized) 1-20 = C1 Dibenzothiophene, C1 Fluorene, C2 Dibenzothiophene, C2 Fluorene, C3 Dibenzothiophene, C3 Fluorene, C4 Dibenzothiophene, C4 Fluorene, Dibenzothiophene, C1 Chrysene, C2 Chrysene, C2 Naphthalene, C2 Phenanthrene, C3 Chrysene, C3 Naphthalene, C3 Phenanthrene, C4 Chrysene, C4 Naphthalene (Butyl), C4 Phenanthrene, and Retene, and PAHs (TOC standardized) 1-12: Acenaphthene, Acenaphthylene, Anthracene, Benz[a]anthracene, Benzo[a]pyrene, Benzo[b]fluoranthene, Benzo[g,h,i]perylene, Benzo[k]fluoranthene, Dibenzo[a,h]anthracene, Fluoranthene, Indeno[1,2,3-c,d]pyrene, and Pyrene, respectively. Samples A1-10, S1-10, and N3-4 are from SS1, SS2, and RS1, respectively.

For the blueberry soil samples, we identified four PCs which together explain 91.8 % of the total variance, suggesting that they capture almost the entirety of the environmental variability found in the blueberry soil samples from sites SS3 and RS2. Figure 10A shows PC1 and PC2, while Figure 10B presents PC3 and PC4. Predominantly, the variance in these soil samples (PC1 accounting for 48.5% of the total variance) is positively influenced by all TEs except zinc, and properties (*i.e.,* CEC, EC, OM, Silt, Clay, Moisture, and total N) and negatively by mainly soil-APAH20, sand, and pH. While hydrocarbons, primarily PAHs (*i.e.,* PAH-4-8, 11, and total), and the total APAHs content including APAH2 is more aligned with PC2. The impact of APAHs (*i.e.,* APAH-12, 13, 14, 15, 16, and 18) is less pronounced on the overall variance and are represented by PC3. Outliers, particularly zinc are characteristics of PC4.

Samples from SS3 (except K5) are aligned in the positive direction of PC1. A subset of samples from both SS3 and RS2, specifically samples N1, K1-4, and K5, are positively characterized by variables associated with PC2. Although, a clear clustering pattern of the sampled sites in the direction of PC3 is not evident, a scattered but distinct cluster of certain SS3 samples (*i.e.,* K2, K4, K6) are positively aligned with PC4.

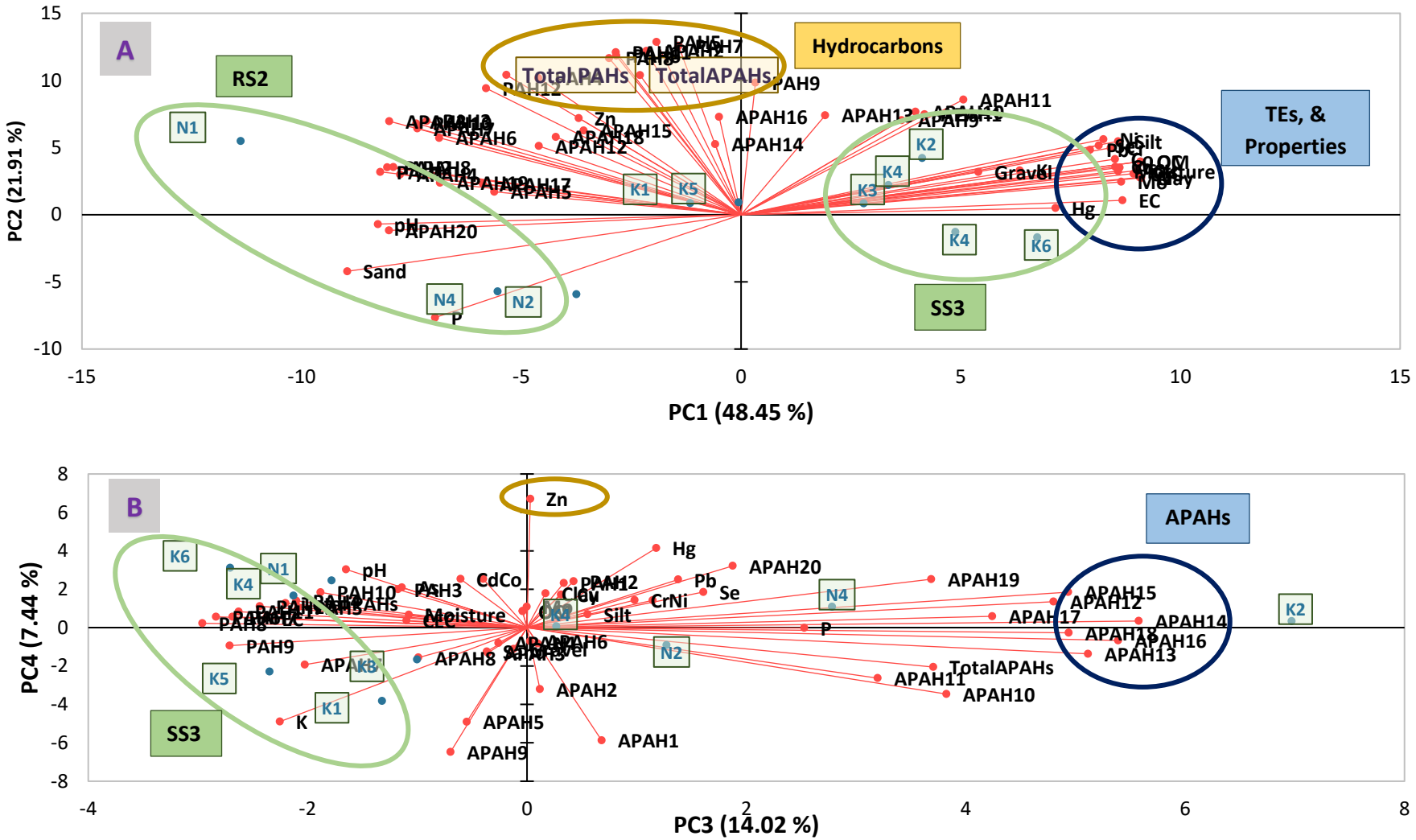

Figure 10: Principal components analysis (PCA) biplots for environmental variables analyzed in blueberry collected Soil samples from Fort McMurray, Alberta, 2022 for (A) PC1-2, and (B) PC3-4. Blue dotted Green squares Represent Individual Soil Samples (n = 15). Red lined Black Vectors Indicate Individual environmental variables. APAHs (TOC standardized) 1-20 = C1 Dibenzothiophene, C1 Fluorene, C2 Dibenzothiophene, C2 Fluorene, C3 Dibenzothiophene, C3 Fluorene, C4 Dibenzothiophene, C4 Fluorene, Dibenzothiophene, C1 Chrysene, C2 Chrysene, C2 Naphthalene, C2 Phenanthrene, C3 Chrysene, C3 Naphthalene, C3 Phenanthrene C4 Chrysene, C4 Naphthalene (Butyl), C4 Phenanthrene, and Retene, and PAHs (TOC standardized) 1-12: Acenaphthene, Acenaphthylene, Anthracene, Benz[a]anthracene, Benzo[a]pyrene, Benzo[b]fluoranthene, Benzo[g,h,i]perylene, Benzo[k]fluoranthene, Dibenzo[a,h]anthracene, Fluoranthene, Indeno[1,2,3-c,d]pyrene, and Pyrene, respectively. Samples K1-6, and N1, 2 & 4 are from SS3, and RS2, respectively.

In summary, the soil samples collected from pin cherry and blueberry sites exhibited similar characteristics. In both pin cherry and blueberry soils, TEs and properties are primarily associated with soil attributes (PC1), whereas hydrocarbons (PAHs and APAHs) are associated with a separate component, PC2. These are clearly evident in samples from SS2 and SS3, respectively.

For berry samples, we included antioxidant functional variables, chemical concentrations, and physicochemical properties in the PCA analysis. As illustrated in Figures 11A and B, PC1, PC2, PC3, and PC4 together account for 57.1% of the variance in variables associated with the pin cherry fruit samples. A specific set of APAHs (*i.e.,* APAH-3, 5, 10, 11, 18, 20, and total), predominantly contribute to the variance represented by PC1, explaining 27.97% of the total variance. PC2 accounts for 12.54% of the variance, with TEs (As, Mg, Se, B, and Co) and TAC, and pH as the primary moderately strong contributors (positively associated with PC1); most of the other variables, particularly other antioxidants, are considered insignificant contributors to the total variance (see Appendix Table 6). PC3, which accounts for 9.70% of the variance, is influenced by TAA, while PC4, contributing to the least overall variance at 6.85%, is associated with a specific APAH.

In terms of sample clustering, variables related to PC1 positively characterize SS1 samples. For PC2, most samples from SS1 (except A5, 9, and 10), SS2 (except S2 and 8) are positively clustered. Moving to PC3 and PC4, patterns in site clustering is less distinct.

For blueberries, the first four principal components account for 75.13% of the total variance in environmental variables derived from fruit samples, as depicted in Figures 12A and B. All PAHs predominantly influence PC1 and is responsible for 31.80% of the variance. Specific APAHs (APAH-1, 2, 5, 10, 13, 15, and total) have a strong association with PC2. TEs (*i.e.,* As, B, Cd, Cr, and Pb) strongly associated with PC3 explaining 13.44% of the variance. Additionally, TPC, APAH14, and APAH18 strongly correlated with PC4 which accounted for 8.57% of the variance.

In terms of sample clustering, most SS3 samples (except K1 and K3) and RS2 (except N1) oriented in the negative direction of PC1. While PC2 is positively characterized by these samples (K1,K2, K4, K6, N2, and N4). Certain SS3 (K5, K6) and RS2 (N1 and N4) samples clustered negatively and positively, respectively with PC3, while RS2 samples cluster positively with PC4.

In summary, there is a clear clustering pattern for APAHs in pin cherry fruit samples, particularly those collected from SS1. In comparison, the PAHs are clustering together in blueberry fruits, however SS3 and RS2 samples showed opposite characteristics. Additionally, TEs and specific fruit quality variables are linked with pin cherries, especially from SS1. While APAHs are predominately linked (negative association) with blueberries from both sampled sites.

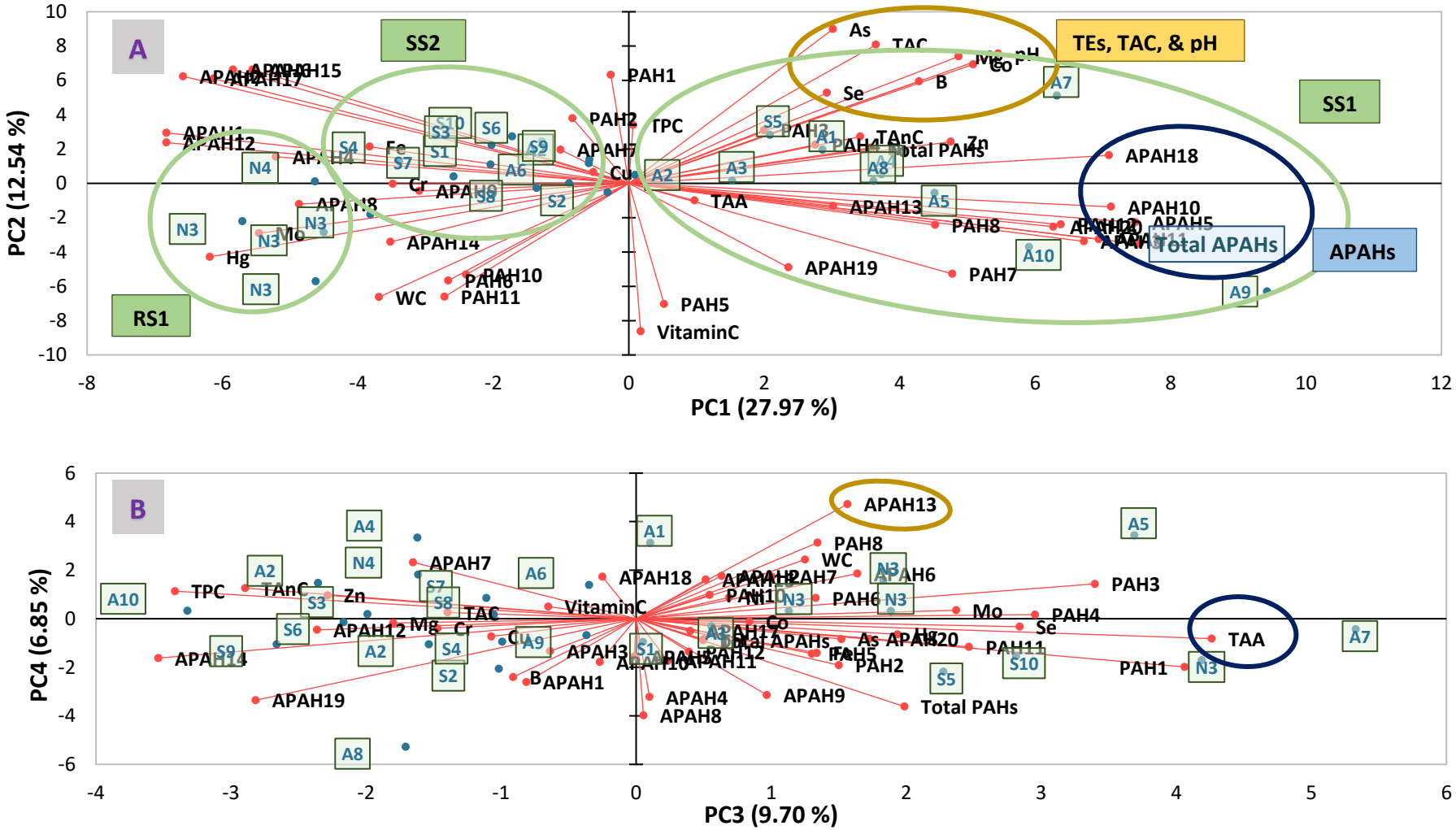

Figure 11: Principal components analysis (PCA) biplots for environmental variables analyzed in pin cherry fruit samples from Fort McMurray, Alberta, 2022 for (A) PC1-2, and (B) PC3-4. Blue dotted Green squares Represent Individual Fruit Samples (n = 26). Red lined Black Vectors Indicate Individual environmental variables. APAHs (TOC standardized) 1-20 = C1 Chrysene, C1 Dibenzothiophene, C1 Fluorene, C2 Chrysene, C2 Dibenzothiophene, C2 Fluorene, C2 Naphthalene, C2 Phenanthrene, C3 Chrysene, C3 Dibenzothiophene, C3 Fluorene, C3 Naphthalene, C3 Phenanthrene, C4 Chrysene, C4 Dibenzothiophene, C4 Fluorene, C4 Naphthalene (Butyl), C4 Phenanthrene, Dibenzothiophene, and Retene, and PAHs (TOC standardized) 1-12: Acenaphthene, Acenaphthylene, Anthracene, Benz[a]anthracene, Benzo[a]pyrene, Benzo[b]fluoranthene, Benzo[g,h,i]perylene, Benzo[k]fluoranthene, Dibenzo[a,h]anthracene, Fluoranthene, Indeno[1,2,3-c,d]pyrene, and Pyrene, respectively. Samples A1-10, S1-10, and N3-4 are from SS1, SS2, and RS1, respectively.

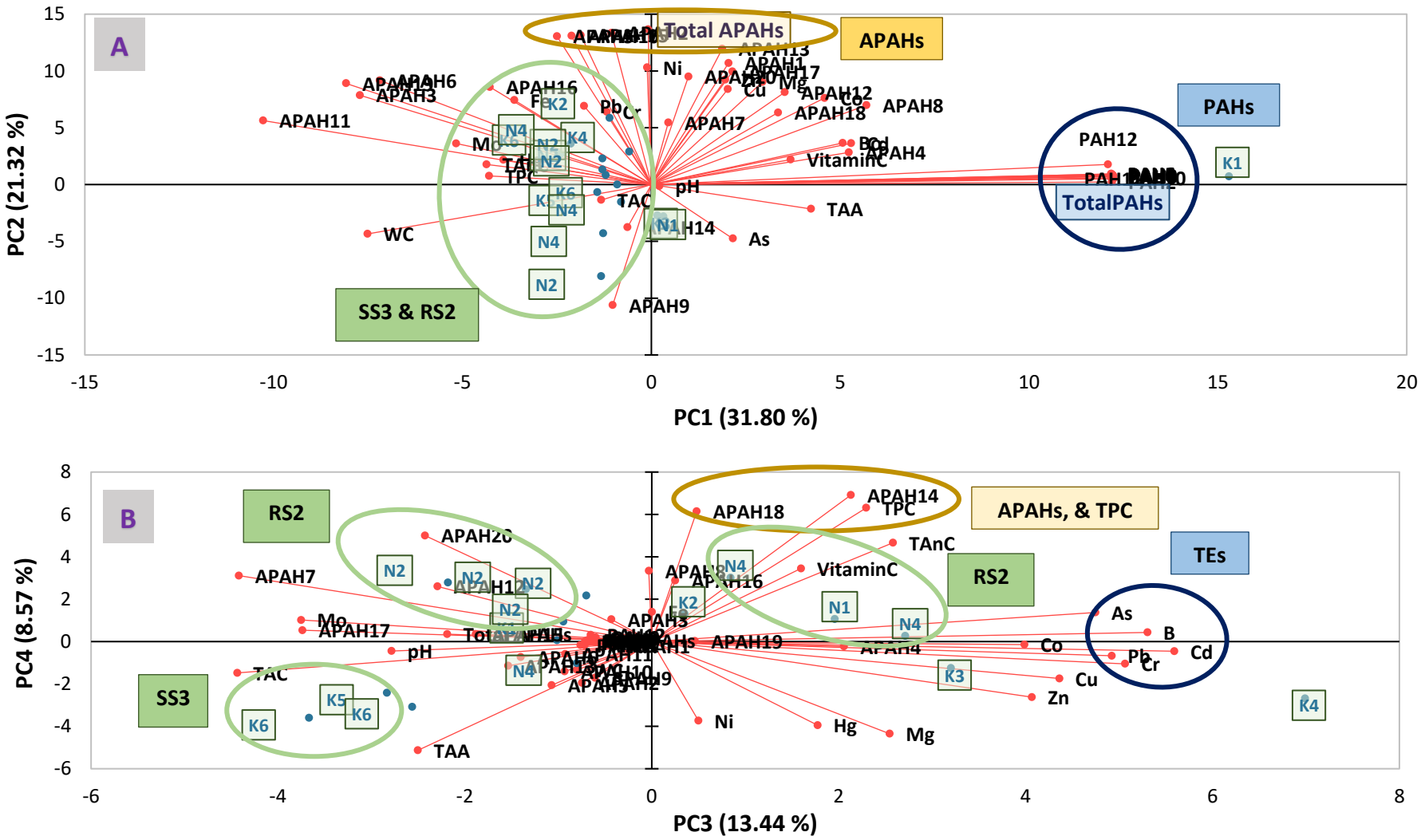

Figure 12: Principal components analysis (PCA) biplots for environmental variables analyzed in blueberry fruit samples from Fort McMurray, Alberta, 2022 for (A) PC1-2, and (B) PC3-4. Blue dotted Green squares Represent Individual Fruit Samples (n = 15). Red lined Black Vectors Indicate Individual environmental variables. APAHs (TOC standardized) 1-20 = C1 Chrysene, C1 Dibenzothiophene, C1 Fluorene, C2 Chrysene, C2 Dibenzothiophene, C2 Fluorene, C2 Naphthalene, C2 Phenanthrene, C3 Chrysene, C3 Dibenzothiophene, C3 Fluorene, C3 Naphthalene, C3 Phenanthrene, C4 Chrysene, C4 Dibenzothiophene, C4 Fluorene, C4 Naphthalene (Butyl), C4 Phenanthrene, Dibenzothiophene, and Retene, and PAHs (TOC standardized) 1-12: Acenaphthene, Acenaphthylene, Anthracene, Benz[a]anthracene, Benzo[a]pyrene, Benzo[b]fluoranthene, Benzo[g,h,i]perylene, Benzo[k]fluoranthene, Dibenzo[a,h]anthracene, Fluoranthene, Indeno[1,2,3-c,d]pyrene, and Pyrene, respectively. Samples K1-6, and N1, 2, & 4 are from SS3, and RS2, respectively.

We also employed PCA analysis to investigate the relationship between soil variables and the attributes of the berry fruits.

Figure 13 (and appendix table 10 with loadings) presents a PCA biplot that displays soil variables alongside the physicochemical properties of pin cherry samples (fruits and soil) from selected sites in 2022. PC1 and PC2, combined, describe 37.36% of the total variance, as depicted in Figure 13A. PC3 and PC4 contributed to 31.97% of the total variance, as shown in Figure 13B.

PC1, which explains 19.58% of the total variance in pin cherry samples, is dominantly influenced by soil attributes, specifically TEs (*i.e.,* Cd, Pb, Cu, and Se) and properties (*i.e.,* CEC, OM, Silt, Clay, total K, total N, and Moisture). PC2, responsible for 17.78% of the variance, is tied to soil APAH20 and Phosphorus (P). Although the patterns of variables associated with PC3 and PC4 are less clear and cover a smaller total variance (14.43% and 7.54%, respectively), these two PCs are primarily observed to be associated with soil APAHs (see appendix table 10).

Distinct clustering is observed with certain samples: SS2 (except S2 and 7) and RS1 for PC1, and certain samples from SS1 (A2, 3, 4, 5, and 6) and RS1 for PC2. The distinction in sample clustering becomes blurrier for the other two PCs, however most SS2 samples show positive alignment with PC3.

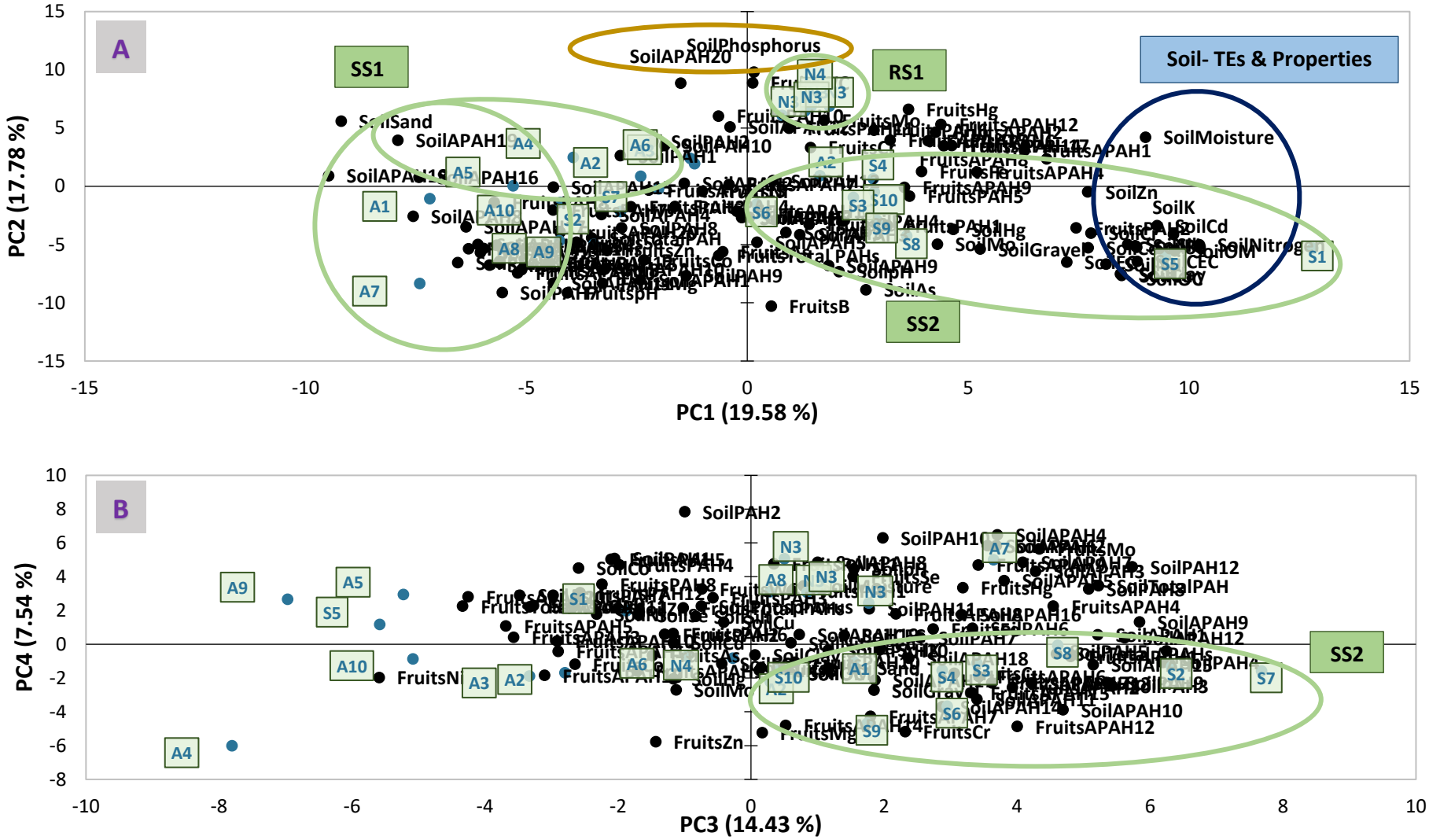

Figure 13: PCA biplot of environmental variables (soil chemicals, properties, and fruit physicochemical properties) from pin cherry samples collected in Fort McMurray, Alberta, in 2022. Part (A) shows PC1-2, while part (B) displays PC3-4. Blue dotted Green squares represent individual soil samples (n = 26), and Black Dots indicate various environmental variables. Soil and Fruit APAHs (TOC standardized) 1-20 (See Figure 9 & 11 Title), and PAHs (TOC standardized) 1-12 (See Figure 9 & 11 Title). Samples A1-10, S1-10, and N3-4 are from SS1, SS2, and RS1, respectively.

Figure 14 (and appendix table 11 with loadings) displays a PCA biplot representing soil variables alongside fruit physicochemical properties for blueberry samples from sites SS3 and RS2 in 2022. PC1 and PC2, account for 48.37% of the total variance (Figure 14A), while PC3 and PC4 together represent 24.91% of the total variance (Figure 14B).

Concentrations of TEs (excluding Zn and Hg), properties (except gravel), and some APAHs (APAH-1, 9, 10, and 11) in the sampled blueberry soil are primarily associated with PC1 (See appendix table 11 for loadings). This accounts for 29.12% of the total variance in blueberry samples. Conversely, all PAHs in the fruit samples correlate with PC2, which explains 19.25% of the overall variance. PC3 associations are more scattered and less clear, however PC4 exhibits a strong correlation with specific APAHs (APAH-8, 13, and 20) from the sampled blueberry fruits.

All samples from SS3 are aligned with PC1, whereas those from RS2 oppose the direction of PC1. Site patterns become less distinct in higher PCs, however certain SS3 samples (K1, K3, and K4) are positively aligned with PC2.

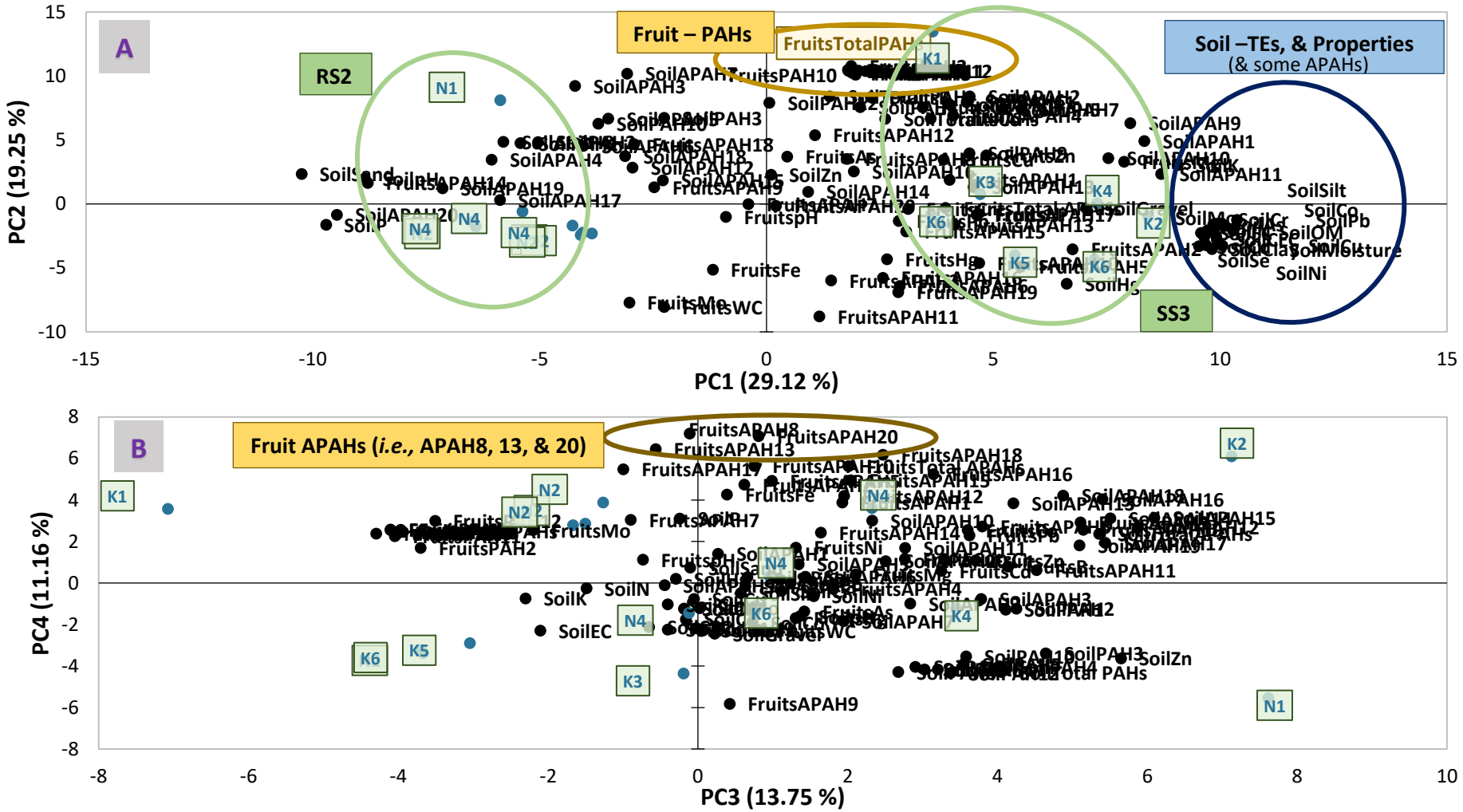

Figure 14: PCA biplot of environmental variables (soil chemicals, properties, and fruit physicochemical properties) from blueberry samples collected in Fort McMurray, Alberta, in 2022. Image (A) shows PC1-2, while Image (B) displays PC3-4. Blue dotted Green squares represent individual soil samples (n = 15), and Black Dots indicate various environmental variables. Soil and Fruit APAHs (TOC standardized) 1-20 (See Figure 10 & 12 Title), and PAHs (TOC standardized) 1-12 (See Figure 10 & 12 Title). Samples K1-6, and N1, 2, and 4 are from SS3, and RS2, respectively.

In summary, both types of berry samples are more strongly associated with soil Trace Elements (TEs) rather than fruit attributes (PC1). The fruit attributes analyzed include chemicals (TEs and hydrocarbons) and physicochemical properties. Notably, certain Alkylated Polycyclic Aromatic Hydrocarbons (APAHs) in the soil are predominantly associated with blueberry samples (PC1) and, to a lesser extent, with APAHs in their fruits (PC2). This pattern is especially evident in blueberry samples from site SS3.

D. Relationship between environmental attributes in fruits and soil and antioxidants in the berries

Regression analysis was conducted to investigate the potential influence of environmental variables represented in PCs (PC1-4) in fruits and soil (Figures 13 and 14) on the analyzed antioxidants (TAnC, TAC, TAA, TPC, and Vitamin C) in the sampled fruits of both berry types.

The regression model indicates that TAA and TAC were the only antioxidant function indicators in the pin cherry fruit samples from selected sites in 2022 significantly ($p < 0.05$) influenced by the environmental variables encompassed by the four PCs discussed in this study (See appendix table 21a). Specifically, the variables within PC4 and PC2 had a significant impact on TAA and TAC levels, respectively in these samples (Figures 15A and B). As shown in Figure 13, the variables that strongly correlated in PC2 were primarily APAH20 and total P in pin cherry soil samples, while those in PC4 didn't show clear patterns of correlations with the environmental variables. Nevertheless, the regression model demonstrates that for each unit increase in PC4, TAA in these fruit samples rose by 0.06 units (Beta = 0.06), while its TAC decreased by 0.02 units (Beta = -0.02) for each unit increase in PC2 (See appendix table 21b and c). Furthermore, the variables within PC4 and PC2 explained 21.0% and 30.0% of the variance in TAA and TAC, respectively. These findings suggest that TAC in pin cherry is primarily influenced (negatively) by the elements and properties found within the soil samples, while their TAA is positively influenced by minor/insignificant contributors of their sampled pin cherry environment. However, notably, over 70% of the variance in TAA and TAC in these samples is attributed to factors not represented by these components.

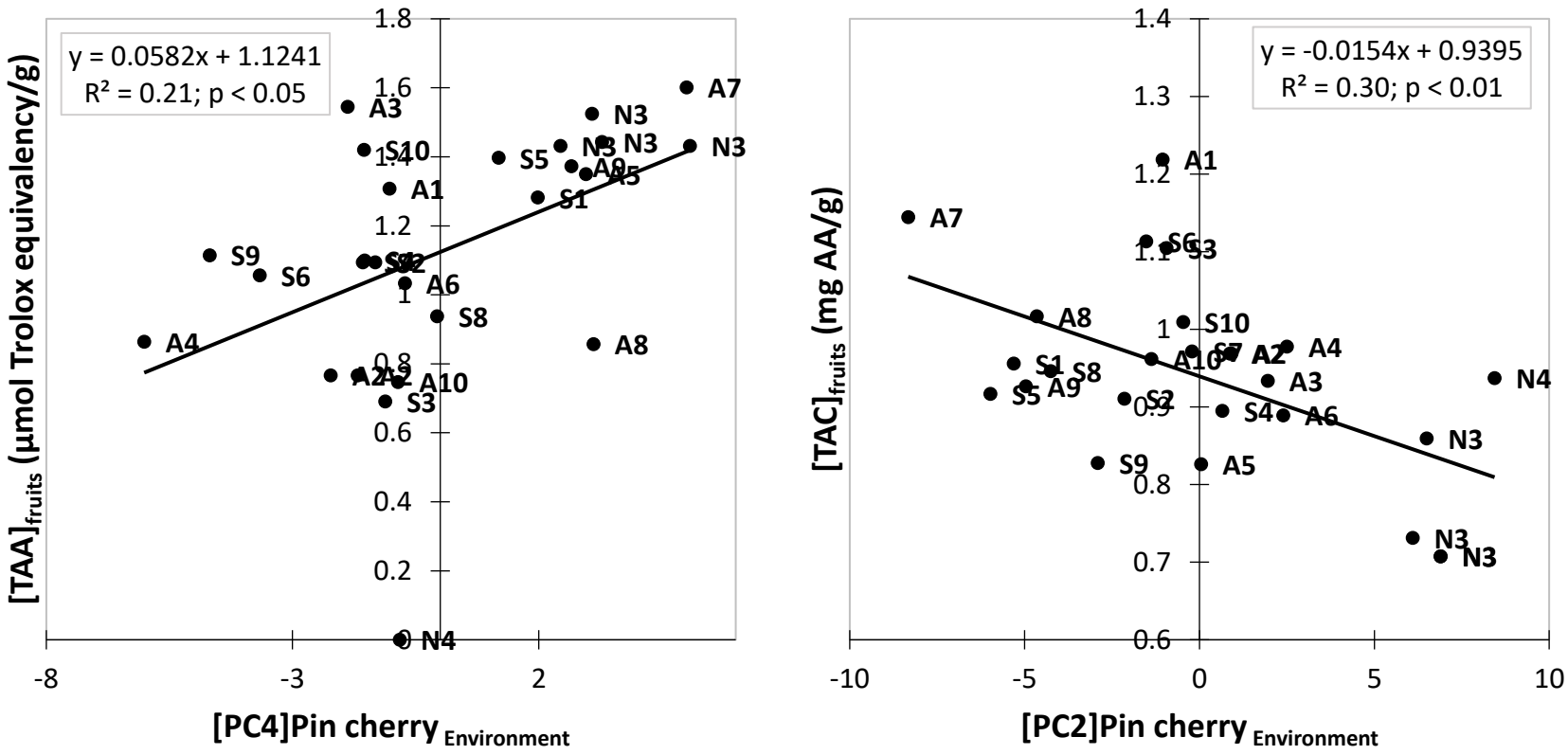

Figure 15: Scatter plot illustrating the regression between the mean concentration of Total Antioxidant Activity (TAA; µmol Trolox equivalency/g), and total antioxidant capacity (TAC; mg AA/g) in sampled pin cherry fruits and the environmental variables representing PC4 (Left) and PC2 (Right) from figure 13 in the pin cherry samples from the studied sites (SS1, SS2, RS1). These variables show a significant regression ($R^2 = 0.21$ and 0.30; $p < 0.05$). Each plot includes the equation of the line (y = mx+b), r^2, and the regression line. All the variables in the plot are transformed based on their normality.

For blueberry samples, TPC in the fruits was the only antioxidant showing a significant ($p < 0.05$) correlation with the four primary PCs (See appendix table 22a). PC1 and PC3 had a significant impact on the TPC concentrations in these blueberry samples (particularly evident in SS3 aligned with PC1) from 2022 ($p < 0.05$; Figure 16). The variables strongly associated with PC1 are TEs, properties, some APAHs in the soil samples, while PC3 did not show strongly distinct association patterns with environmental variables, as depicted in Figure 14. The regression model demonstrates that for each unit increase in PC1 and PC3, TPC in these fruit samples decreased by 0.19 units (Beta = -0.19) and increased by 0.22 units (Beta = 0.22), respectively (See appendix table 22a). As shown in Figure 14, the variables in PC1 and PC3 explain a mere 29.12% and 13.75%, respectively of the variance in the TPC concentrations of these fruit samples. This suggests that the TPC in the sampled blueberries is negatively influenced by soil attributes, mainly elements and soil properties, while minor influencers of their environment also have a positive impact on the TPC in these berries. However, a large portion of the variance, 63-76%, in TPC in these samples remains unaccounted for by the variables represented in these two PCs.

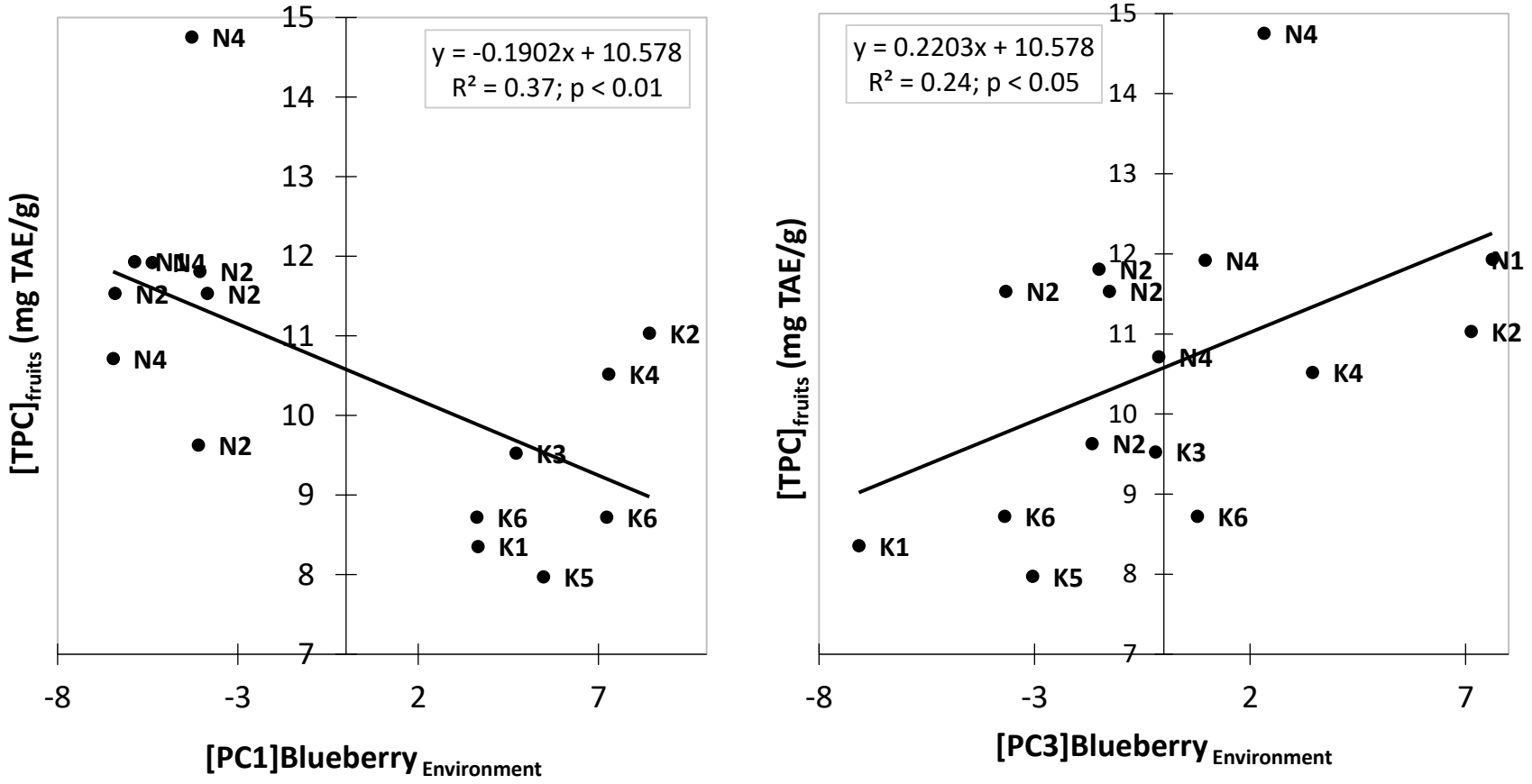

Figure 16: Scatter plot illustrating the regression between the mean concentration of total phenolic content (TPC; mg TAE/g) in sampled blueberry fruits and the environmental variables in blueberry samples representing PC1 (Left) and PC3 (Right) from figure 14 from the studied sites (SS3, RS2). These variables show a significant regression ($R^2 = 0.37$ and 0.24; $p < 0.05$). Each plot includes the equation of the line ($y = mx+b$), r^2, and the regression line. All the variables in the plot are transformed based on their normality.

Overall Key Findings:

- **Soil Differences Based on Site Type:**
    - Reclaimed sites have higher concentrations of PAHs (including APAHs) compared to natural sites.
- **Soil Differences Based on Berry Type:**
    - Blueberry soil samples exhibited higher PAH concentrations than pin cherry soil.
- **Chemical Concentrations:**
    - Soil samples generally had higher chemical concentrations than fruits.
    - Fruits (both berry types) from reclaimed sites exhibited higher concentrations of chemicals and fruit quality variables, compared to natural sites.
    - Only Cu and Fe in fruit samples from select sites exceeded guideline limits.
- **Chemical Associations:**
    - Only a weak negative correlation between Mo in fruits and in their corresponding soil samples was observed:
        - APAH14 in blueberry fruits showed a strong negative and positive relationship with different TEs and organic carbon-standardized APAHs, respectively in the soil, explaining 76% and 77%, respectively of the variance in fruit.
        - APAH9 in pin cherry fruits was significantly linked to specific APAHs in the soil ($R > 0.82$).
- **PCA Observations:**
    - Pin cherry and blueberry soil samples, mostly from reclaimed sites, were primarily associated with TEs and properties.
    - Fruits from reclaimed sites showed varied associations, with pin cherries correlating with alkylated PAHs, and blueberries correlating with parent PAHs.
    - Among antioxidants, TAC concentrations in pin cherry fruits from reclaimed sites were less dominantly but significantly associated with, and they were higher than the natural site.
    - Broadly, the pin cherry environment was mostly linked with TEs and properties in soil. In contrast, the blueberry environment, primarily from reclaimed sites, had a strong correlation with TEs and properties, and specific APAHs in soil.

- **Regression Analysis:**
    - TAA in pin cherries showed a significant association with minor influencers of their sampled environment, while their TAC was strongly influenced by APAH20 and Phosphorus in pin cherry soil, explaining 21% and 30% of TAA and TAC, respectively variance.
    - TPC in blueberry fruits had a strong associations with minor influencers and primarily soil-TEs, properties, and some APAHs contributing to the blueberry environment, explaining 24% and 37% of the TPC variance, respectively.

CHAPTER 4. DISCUSSION

This study aims to investigate the potential influence of environmental factors on health metrics by analyzing the relationship between chemicals, soil properties, and fruit quality parameters in berry fruits and soil samples. Since there is no baseline data available, we have limited the scope of the study to focus on finding patterns and modelling the relationship between these variables measured in berry fruits and soil gathered from four different sites (3 Syncrude oil sands (OS) reclaimed sites and 1 natural site) within Fort McMurray region in 2022. We also focus on assessing the health-focused nutritional quality of pin cherry and common blueberry (also referred to as blueberry) species collected from these sites, with a particular emphasis on antioxidants as the primary health metric.

It is important to highlight that the polyphenolic antioxidants assessed in this study, were extracted using water instead of commonly used organic solvents (Marjanovic *et al.,* 2021). This methodological choice is significant because recent findings have indicated that organic solvent extraction often leads to increased bioaccessibility of antioxidants, a condition that is not typically achieved through consumption (Marjanovic *et al.,* 2021). Conversely, water extraction has been shown to improve cell tissue permeability, thereby facilitating a higher recovery of water-soluble, biologically active antioxidants (Marjanovic *et al.,* 2021). This approach more accurately reflects a likely consumption setting, providing a more realistic assessment of the antioxidants' availability, important in the context of consumption (Marjanovic *et al.,* 2021).

Soil and fruit quality at berry collected Fort McMurray sites

A. ***Soil***

Due to the small sample sizes collected at certain sites, statistical comparisons were not conducted. However, the descriptive statistics of different chemicals and other important environmental variables reported at each site for each berry type illustrate the general trend of environmental quality in different sites (reclaimed vs. natural) in Fort McMurray (Wang *et al.,* 2021). Since this thesis serves as a baseline study, future studies could build on these results by adding more samples and conducting appropriate statistical comparisons.

In the context of soil quality, certain reclaimed sites where pin cherry and blueberry samples were collected (SS2 and SS3), showed the highest chemical concentrations of soil properties and chemicals, particularly TEs and hydrocarbons (Table 1a and 2a). In contrast, the corresponding natural sites (RS1 and RS2), had the lowest concentrations. This suggests variations in soil quality between these site types (natural vs reclaimed), even though they exist within the same region of Fort McMurray. The presence of higher concentrations of well-known contaminants, such as PAHs and toxic elements (*i.e.,* chemicals with no known essential biological role in plants), in OS reclaimed sites could negatively impact the health of surrounding vegetation (Unaegbu *et al.,* 2016). We did not statistically compare the chemical concentrations between the natural and the reclaimed sites because of the limited number of sites within each group. However, the results of the PCA analyses show that the natural sites and the reclaimed sites clustered separately based on their variability in chemical concentrations and soil properties. Such findings suggest that the reclamation process, especially in SS2 (Sandhill) and SS3 (Kingfisher), may take a longer time to reach to a state that is more similar to the natural sites.

Reclaimed sites, especially SS3 where both berry types were collected, showed higher concentrations of most soil properties, possibly due to controlled reclamation strategies, while natural sites develop organically (Wellstead *et al.,* 2016). It would be helpful to determine whether mimicking these natural soil conditions in Fort McMurray through reclamation would enhance overall soil quality, particularly to promote the health and growth of berries (Wellstead *et al.,* 2016). However, in pin cherry soil samples, an inverse relationship was observed between the two site types (SS2 and RS1) regarding certain soil properties (sand, total P, and moisture; Table 1a). The elevated concentrations of these attributes in the sampled natural areas of Fort McMurray suggest that their soil particles are coarse. Yet, they retain more moisture and macronutrients, in areas where pin cherries grow (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Conversely, the Sandhill reclaimed site displayed a different pattern. This is in contrast to findings from literature studies that indicate finer-textured soils better retain nutrients and moisture (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Although research has shown that sandy soils can enhance their retention of water and nutrients by incorporating more OM, the results (Table 1a) indicate that OM is lower in the natural sites (2.36%) compared to the reclaimed sites (SS2 = 4.26%) (Mackenzie, 2006 and 2012; Khadka, 2016; Grzebisz *et al.,* 2022; Sun *et al.,* 2019). This indicates that the strategies employed in the reclaimed sites have led to these specific soil condition patterns, differentiating them from natural settings (Mackenzie, 2006 and 2012; Khadka, 2016; Grzebisz *et al.,* 2022; Sun *et al.,* 2019). This accentuates the importance of focusing on reclamation strategies that prioritize soil texture, moisture retention, and Phosphorus (P) enrichment to determine if these adjustments can promote pin cherry growth and development in reclaimed areas (Liu *et al.,* 2022).

Potential toxic COCs (*i.e.,* Hg, Cd) remained consistent across all pin cherry sampled sites or between specific reclaimed and natural sites (Table 1a; Unaegbu *et al.,* 2016). This suggests that the presence of these chemicals is widespread across both types of sites and that their origin might be widespread rather than site-specific (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). The broad range of concentrations, especially in PAHs (primarily the alkylated derivatives), in soil samples from both berry types, predominantly from reclaimed sites (SS2 and SS3), points to variability in soil conditions within different areas of the same site (Table 1a and 2a; Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). This suggests that reclamation strategies might vary across these sites, resulting in elevated concentrations of highly toxic and persistent PAH compounds in some areas compared to others (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Thus, future studies should focus on the hydrocarbon variability within reclaimed sites. In contrast, soil sampled areas of natural sites (RS1 and RS2) exhibited no (or very small) such variations in concentration, particularly for TEs (Table 1a and 2a; Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). This implies consistency in soil conditions in natural lands where pin cherries, in particular, are grown (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013).

Furthermore, soils from blueberry sites compared to pin cherry sites, exhibited elevated concentrations of soil attributes, including soil properties and hydrocarbons (Table 1a and 2a; (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). This indicates distinct soil variability between the sites where different berry types are cultivated (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). It suggests that the soil conditions favorable for blueberries in Fort McMurray might be less effective at reducing PAH concentrations compared to those where pin cherries grow (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Notably, natural sites where pin cherry samples were gathered had higher concentrations of both essential and non-essential TEs than blueberry grown natural sites (Unaegbu *et al.,* 2016).

This implies that the soil of natural habitats where pin cherries grow are richer in nutrients essential for their growth (Unaegbu *et al.,* 2016).

B. ***Fruits***

In the fruit samples, attributes in reclaimed fruits (from both berry types), which include chemicals (TEs and PAHs) and fruit quality variables (antioxidants, pH, and water content), were found to be higher in concentration than in natural berries (Tables 1b and 2b). This suggests that reclaimed berry fruits have absorbed a wide range of both beneficial and potentially toxic chemicals (Unaegbu *et al.,* 2016; Al-Farhan *et al.,* 2023). The elevated concentrations of certain antioxidants, increased acidity, and moisture indicate that these fruits are responding to environmental conditions distinct from those experienced by naturally grown berries in Fort McMurray (Kasote *et al., 2015*). Interestingly, the content of anthocyanins (pigments), and overall antioxidant capacity were higher in reclaimed pin cherries (SS1) compared to their natural fruits (Tables 1b). This suggests that reclaimed pin cherries from the Aurora site might be brighter and contain antioxidants like anthocyanins, that have a heightened ability to counteract oxidative stress (Gest *et al.,* 2013; Liu *et al.,* 2018; Gramza-Michałowska *et al.,* 2019; Dong *et al.,* 2022). Conversely, pin cherry samples from SS2 showcased higher concentrations of phenolics and an elevated overall antioxidant activity (Tables 1b). This implies that antioxidants, especially phenolic compounds in these berries from this particular reclaimed site, have an enhanced capability to neutralize free radicals under stress conditions (Dai and Mumper, 2010; Gramza-Michałowska *et al.,* 2019; Dong *et al.,* 2022).

When comparing the two sampled berry types, blueberry fruits from natural sites had higher concentrations of hydrocarbons, antioxidants, and physicochemical properties than their natural

pin cherry counterparts (Tables 1b and 2b). Conversely, natural pin cherry fruits exhibited elevated concentrations of essential TEs (*i.e.,* Mg, Cu, Se, Mo, and Zn) (Tables 1b and 2b; Unaegbu *et al.,* 2016). This pattern suggests that in natural settings, blueberries tend to accumulate harmful chemicals, while pin cherries predominantly absorb nutrients (Unaegbu *et al.,* 2016). Thus, the fruit quality variables of these berries show distinct responses to environmental stressors, even when both types are grown in natural sites (Unaegbu *et al.,* 2016). Moreover, reclaimed blueberries displayed lower chemical (both essential and non-essential) concentrations, and lower fruit quality variables compared to reclaimed pin cherries (Tables 1b and 2b). This indicates that, environmental conditions in these lands seem to negatively affect reclaimed blueberry fruit composition, influencing chemicals including non-essential hydrocarbons, but also antioxidants, and physicochemical properties important for health and nutritional quality (Li *et al.,* 2008).

Certain chemicals (*i.e.,* Benzo[a]pyrene, As, Hg, and Se) in pin cherries were consistent across the selected sites (Tables 1b), suggesting that their concentrations remain stable, indicating minor environmental differences between these locations (Shange *et al.,* 2012). Notably, elements like As, Hg, and Cd, which showed negligible concentrations in the fruit samples (particularly Table 1b), imply that these potentially harmful chemicals are not accumulating in large amounts within the fruits (Zhao *et al., 2022*; Molina and Segura, 2021). This is of particular importance since if these chemicals were to accumulate at high levels, they might exceed guideline limits, posing potential health risks (Codex alimentarius commission, 2007; European Commission, 2007-2023). For antioxidants such as Vitamin C in both berry types (and APAH compounds in blueberries specifically), there were notable concentration variations within the site, especially in samples from reclaimed sites (Tables 1b and 2b). This variability underscores the differing impacts of reclamation strategies on the antioxidant and hydrocarbon content of these berries (Cosia Land EPA, 2017). Such disparities also spotlight the differences in environmental conditions within the reclaimed site. Conversely, the most consistent fruit sample results were observed in natural sites

(Tables 1b and 2b), indicating more uniform environmental conditions in these areas (Cosia Land EPA, 2017). Additionally, compared with the soil samples for each berry type, the corresponding fruit samples had lower concentrations of the same chemicals (Tables 1-2); this difference underscores the importance of investigating if there's a relationship between the chemicals in the soil and those in the berry fruits from the select sites in Fort McMurray.

Guideline limits: Berry and soil quality in Fort McMurray, 2022

A. Soil Quality

The Canadian Council of Ministers of the Environment (CCME) and the Government of Alberta have established soil quality guidelines for environmental health (SQG_E) and Alberta's Tier 1 Soil Remediation Guidelines for 2022-2023. These guidelines regulate the levels of chemicals (TEs and PAHs) in different land uses, with agricultural land use being the primary focus of this study (Canadian soil quality guidelines, 2007; Milligan and Branch, 2022). Concentration limits for TEs and both non-carcinogenic and carcinogenic PAHs are detailed in the appendix (Refer to appendix Table 12). Notably, there are no established soil quality guidelines to protect environmental health concerning total PAHs and alkylated derivatives of parent PAHs. This absence stems from a lack of sufficient data to set definitive soil contact guidelines (Canadian soil quality guidelines, 2010; Milligan and Branch, 2022). In our study, all measured concentrations of TEs and individual PAHs in soil samples from each site (SS1, SS2, SS3, RS1, RS2) fell below their respective guideline values (Tables 1a and 2a), suggesting that soil from the selected Fort McMurray sites in 2022 meets acceptable standards for agricultural land use (Canadian soil quality guidelines, 2010; Milligan and Branch, 2022). This implies that the sampled soil carries a diminished likelihood of environmental contamination (Canadian soil quality guidelines, 2010; Milligan and Branch, 2022). However, more research is essential to evaluate potential environmental health risks posed by the

presence of total PAHs and alkylated PAHs in the soil, especially given the current lack of comprehensive guideline limits for these compounds (Canadian soil quality guidelines, 2010; Milligan and Branch, 2022).

B. Fruit Quality

The maximum allowable limit (MAL) in food for TEs and PAHs plays a pivotal role in safeguarding consumer health (Codex alimentarius commission, 2007; European Commission, 2007-2023). These established limits ensure that consumers ingest the right amounts of these chemicals, regardless of whether they are essential nutrients or non-essential for fruit growth and development, thus mitigating the risks of overconsumption (Codex alimentarius commission, 2007; European Commission, 2007-2023). Both the WHO/FAO and the EU have established MALs in food for specific TEs, including As, Cd, Cu, Pb, Fe, and Hg, as well as for PAHs, particularly Benzo[a]pyrene and the combined total of benzo[a]pyrene, benzo[a]anthracene, benzo[b]fluoranthene, and chrysene (appendix Table 13) (Codex alimentarius commission, 2007; European Commission, 2007-2023). It is worth noting that certain chemicals, such as As, Cu, Fe, and specific PAHs, currently lack defined MALs in the guidelines for small fruits and berries (Codex alimentarius commission, 2007; European Commission, 2007-2023). For the purposes of this study, the limits most closely aligned with the berries tested were utilized for comparison (refer to appendix Table 13) (Codex alimentarius commission, 2007; European Commission, 2007-2023). Overall, the mean concentrations of most TEs (mg/Kg) and PAHs (ng/g) in the fruit samples from this study did not exceed their respective MALs (see appendix Tables 1 and 3) (Codex alimentarius commission, 2007; European Commission, 2007-2023). However, the Fe and Cu levels in fruit samples from the Fort McMurray sites in 2022 did surpass their MALs set for edible vegetable oils (Figure 5) (Codex alimentarius commission, 2007; European Commission, 2007-2023). However, the toxicity of Cu and Fe is low. The upper limit is 10 mg for Cu and 45

mg for Fe (Trumbo *et al.,* 2001), which will take a consumer at least 3.1 and 4.7 Kg of pin cherries and 8.3 and 1.8 Kg of blueberries (from the sampled fruits) per day to reach the upper limits, respectively. Therefore, the current TE and PAH concentrations in the berries collected from the sampling site should pose minimal risk to the consumers. However, it remains essential to consistently monitor the nutrient levels in Fort McMurray's berries, ensuring they stay within acceptable boundaries to prevent potential health hazards for consumers (Codex alimentarius commission, 2007; European Commission, 2007-2023).

Association between berry fruits and soil

The results presented here only report significantly strong correlations ($R \geq 0.8$ and ≤ -0.8) between chemicals in soil and fruits, as shown in Tables 3-6 and Figures 6-8 (Nujkić *et al.,* 2016). This approach was chosen because a) stronger associations are more likely to yield a relevant impact and meaningful influence on the outcome, even though weaker correlations might still be statistically significant, and b) focusing on these strong correlations helps keep the research aligned with the primary objective of this thesis (Nujkić *et al.,* 2016). Although our Pearson correlation analyses did not detect a significantly strong direct correlation between the concentrations of the same chemicals in the soil and berry fruits (with molybdenum being an exception, though its correlation was significantly weak), they revealed significant associations between different chemicals across these media. Specifically, boron in blueberry and magnesium in pin cherry sampled fruits were significantly associated with different TEs, including HMs in the soil, but these correlations were not strong ($R < 0.8$). However, this highlights the complexity of the soil-to-plant transfer and translocation systems (Liu *et al.,* 2021). It is important to note that the primary aim of these correlation analyses was to identify potential relationships between soil and small plants, such as berry fruits, particularly regarding the transfer of chemicals. These relationships

are crucial for evaluating environmental factors, especially soil-derived ones, that might influence the antioxidant content in berry fruits. However, the main focus of this study was not to establish causality between the concentrations of chemicals in the soil and their presence in berry plants, but rather to understand broader patterns and relationships.

Tables 4-6 show that only the concentration of APAHs in blueberry and pin cherry fruit samples was strongly associated with the concentration of chemicals in their corresponding soil samples. In particular, C4 Chrysene—an alkylated derivative of a High Molecular Weight (HMW) PAH found in blueberry fruits—was negatively associated with TEs, including certain micronutrients (*i.e.,* Co and Cu), and HMs (*i.e.,* As and Cr) in the soil. C4 Chrysene was also positively associated with Low Molecular Weight or LMW alkylated derivatives of PAHs, such as C4 Phenanthrene and Retene in soil (Zhao *et al.,* 2022). It is important to emphasize that PAHs, comprising two or more fused aromatic (benzene) rings, are categorized as LMW with 2-3 rings and HMW with four or more rings (Canadian Council of Ministers of the Environment, 1999; State Water Resources, 2017). The results suggest that TEs and APAHs (despite having different aromatic ring structures) could impact the uptake and accumulation of specific APAHs in blueberry fruit samples (Nujkić *et al.,* 2016).

Scatterplots (Figure 6 and 7) demonstrated that these TEs and alkylated PAHs in the soil accounted for a significant portion of the variance in blueberry fruit's C4 Chrysene concentration, explaining 76 and 77% of it, respectively. Unstandardized values of the TEs and APAHs in the soil were utilized to preserve the original scale of soil-fruit chemical relationships (Schäfer and Schwarz, 2019). Due to varying SOM concentrations in the sampled soil (reclaimed > natural; See Tables 1a and 2a), Total Organic Carbon (TOC) was used to standardize PAH values for more accurate correlations, as OM can bind hydrophobic compounds like PAHs (Ali *et al.,* 2022). Overall data

suggests that these TEs and APAHs in the soil of sampling sites of Fort McMurray profoundly and notably influence the concentration of C4 Chrysene in blueberries cultivated in these areas (Schäfer and Schwarz, 2019). However, C4 Chrysene concentrations are negligible (after 2 decimals), particularly from the reclaimed site (Table 2b) and C4 Chrysene is not significantly influential enough to drive (See PC4 in Figure 12) the overall quality of these sampled blueberry fruits (Further discussed in the PCA section), contributing to 8.6% of the total variance in the samples (Zhao *et al.,* 2022).

In the pin cherry fruit samples, the concentration of another alkylated derivative of HMW Chrysene (C3 Chrysene) exhibited a significant positive correlation ($R > 0.80$) with alkylated LMW PAHs (C2, C4 Dibenzothiophene, and C3 Fluorene) from the corresponding soil (Table 6 and Figure 8) (Liu *et al.,* 2020). This correlation implies that an elevation in soil APAHs content tends to increase C3 Chrysene in the pin cherries, suggesting a relationship between APAHs, even with their differing structures, in both soil and fruits (Liu *et al.,* 2020). Further statistical analysis showcased that 70% ($R^2 = 0.70$) of the variability in fruit C3 Chrysene concentrations derives from the variability in soil LMW APAH levels (Liu *et al.,* 2020). Thus, while these APAHs are significant contributors to C3 Chrysene concentrations in the fruits, 30% of the C3 Chrysene concentration variability is influenced by other factors not considered in this specific regression model (Liu *et al.,* 2020; Hazra and Gogtay, 2016; Wu *et al.,* 2017). The correlation between potentially toxic hydrocarbons is of concern, even if the concentrations of C3 Chrysene in these fruit samples during the sampling period were found to be low (negligible in the natural site) in our study (Table 1b).

Additionally, with the aim of using this data in predictive models for future studies and considering that this study focuses on antioxidants as health indicators in selected berry plants, we conducted

a separate correlation analysis (Paniagua *et al.,* 2013; Yadav and Singh, 2014; Lufu *et al.,* 2020). This analysis examined the associations between different antioxidants in the sampled fruits of each berry species, pooling data from all sites (Paniagua *et al.,* 2013; Yadav and Singh, 2014; Lufu *et al.,* 2020). Our findings indicated that in pin cherry fruits, only the polyphenolic antioxidants showed moderate to weak correlations ($R < 0.8$), whereas in blueberry fruits, polyphenols exhibited significantly strong negative associations ($R < -0.8$), except for Total Phenolic Content (TPC) and Total Anthocyanin Content (TAnC), which showed strong positive correlations ($R > 0.8$) (See Appendix 23 a and b). We also did not find significantly strong associations ($R < 0.8$) between antioxidants and physicochemical properties (pH and water content) (See Appendix 23 a and b). This suggests that interactions between antioxidants differ between berry species; blueberries demonstrate a positive relationship, while pin cherries show an inverse relationship, except for phenolics and anthocyanins, and that the interaction between antioxidants and properties in fruits is not a direct linear relationship (Paniagua *et al.,* 2013; Yadav and Singh, 2014; Lufu *et al.,* 2020; Mediani *et al.,* 2014). These patterns illustrate the unique antioxidant profiles of the two berry species and suggest that antioxidant interactions in pin cherries are more synergistic compared to blueberries (Paniagua *et al.,* 2013; Yadav and Singh, 2014; Lufu *et al.,* 2020). This approach provides insights into how antioxidants interact within the fruits and aids in understanding their combined effects on the plant (Paniagua *et al.,* 2013; Yadav and Singh, 2014; Lufu *et al.,* 2020). It also contextualizes findings from the soil and fruit chemical correlations (Paniagua *et al.,* 2013; Yadav and Singh, 2014; Lufu *et al.,* 2020). This data could be pivotal in future research to elucidate direct or indirect (via association with fruit chemicals) cause-effect relationship pathways between soil chemicals and antioxidant interplay in fruits, enhancing our understanding of the complex pathways through which environmental variables impact fruit antioxidants (Paniagua *et al.,* 2013; Yadav and Singh, 2014; Lufu *et al.,* 2020).

Drivers of Berry and Soil Composition from Fort McMurray, 2022

PCA simplifies data variance to identify key environmental variables, minimizing overfitting for accurate data relationship representation (Ryznar *et al.,* 2022). It groups datasets into components based on variable contribution to variation (Ryznar *et al.,* 2022). Components are ranked by eigenvalues, with the highest indicating the most variation (typically the first component or PC1) (Ryznar *et al.,* 2022). The top four components usually capture main data variations (Ryznar *et al.,* 2022). Variables are linked to components through 'loadings', with strong loadings (≥ 0.7 and ≤ (-)0.7) indicating significant variables (appendix Tables 6-11). If no strong loadings are present, moderately strong loadings (≥0.5 and ≤ (-)0.5) are considered (Ryznar *et al.,* 2022).

Subsequent sub-sections (1 and 2) delve into the environmental variables that influence the composition of berry fruits (pin cherry and blueberry) and the associated soil samples from each study site. Recognizing which factors affect the overall fruit and soil quality is pivotal, especially when it comes to primary environmental variables, as these have a significant impact on the overall health of the environment (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013).

1.) Drivers of soil quality in Fort McMurray

Based on results from Figures 9 and 10, PC1 is the predominant component, accounting for over 31% and 48% of the total variance in pin cherry and blueberry sampled soil, respectively, from their relevant sites studied in 2022 (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). The dominant environmental variables influencing the soil variance of both berries are primarily the TEs and soil properties, with their intercorrelations hinting at a shared origin (Yang *et al.,* 2016). Most of these TEs, such as As, Ni, Se, Cr, Co, Pb, Zn, and Ni, can originate from sources like fossil fuel production, bitumen, dust from open pit bitumen mines (haul road dust), OS upgrader emissions, and oil combustion, especially bitumen fuel combustion (Shotyk, 2022;

Zhang *et al.,* 2022; Phillips-Smith *et al.,* 2017; Spolaor *et al.,* 2021). This suggests a likely common anthropogenic source, potentially OS mining (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Moreover, soil properties, characterized by their ability to hold more exchangeable cations, higher dissolved ion content, and OM, and smaller soil particles that retain more nutrients, play a pivotal role in positively influencing the concentration of these TEs in soil (Wang *et al.,* 2020).

The soil from the pin cherry collection site showed positive associations with PC1, primarily from the SS2 site, a reclaimed area within Syncrude OS (Figure 9) (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Similarly, the SS3 site, another reclaimed area in Syncrude OS where blueberries were collected, displayed comparable trends (Figure 10). These samples exhibit similar soil quality parameters, leading to their grouping and suggesting enriched soil properties and TE concentrations at both SS2 and SS3 sites compared to other select sites, particularly natural ones (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Wu (2015) and Rees *et al.* (2020) noted that the type of reclamation material can alter soil properties. Tailings sand, typically comprising 95% sand, 3% silt, and 2% clay, is common in these sites (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). The addition of organic materials, such as peat-mineral mix, can change particle ratios and OM content, possibly explaining the similar soil properties at both sites, as they contain tailings sand waste in their subsoil layer (Rees *et al.,* 2020).

Furthermore, SS2 and SS3, being relatively more recent sites, exhibit distinct soil properties (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Stutler (2019) found that younger reclaimed West Virginia mine soils, ranging in age from 2 to 32 years, have higher soil pH, OM, and bulk density compared to older sites. This is attributed to younger sites having less development time and thinner soil layers (Stutler, 2019). Yarmuch (2003), as synthesized by Wu

(2015), noted that younger reclaimed OS soils contain varying soil particle levels, with more clay and silt in younger sites. The limited time for natural processes in younger lands can lead to differences in soil properties, influencing chemical accumulation (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Soils with a finer texture, indicating higher clay and silt composition, retain nutrients and moisture more effectively (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Conversely, sandy soils, characterized by low CEC, OM, silt, and clay, have lower water retention capabilities due to large particle size and low surface area (Sun *et al.,* 2019). Our study found primary driving soil properties in reclaimed sites to be finer-textured and OM-enriched. Wu (2015), referencing Yarmuch (2003), observed that topsoil in reclaimed Syncrude OS sites in Alberta (up to 10 cm depth) has higher silt and clay proportions, lower density, and more OM than natural Alberta sites. This underscores the importance of reclamation strategies in shaping soil attributes at SS2 and SS3 (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013).

Soil samples from the natural site in Fort McMurray (RS1 and RS2) and another reclaimed site at Syncrude OS (SS1) exhibited a negative relationship on PC1 (Figure 9). This suggests significant differences in soil properties and TE concentrations between these samples and those from SS2 (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Notably, the natural site used in this study is approximately 30 km from the reclaimed sites (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). This proximity suggests that both natural areas and SS1 share similar TE profiles. Considering their relative distance from other reclaimed sites, the TEs, including HMs identified, might travel considerable distances (Boutin and Carpenter, 2017). Indeed, research has documented the deposition of atmospheric metals within a 50-90 km radius of the Athabasca OS upgraders (Boutin and Carpenter, 2017). Additionally, soil properties of SS1 are more similar to the natural site than to SS2, indicating spatial variations (Shange *et al.,* 2012).

Interestingly, a few samples from the SS1 site register positive values on PC1 (Figure 9) (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). This indicates that the soil properties and TE concentrations in these samples are more closely aligned with those in SS2 soil samples, rather than with samples from their own site, illustrating variability within such a reclaimed site (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). This pattern suggests that SS2 soil samples tend to be driven by higher concentrations of these soil characteristics, while the majority of SS1 and RS1 samples are influenced by reduced levels of these characteristics (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013).

PC2, while significant, is less dominant than PC1, accounting for over 24% of the total variance in pin cherry soil and 22% in blueberry soil samples (Figures 9 and 10) (Lever *et al.,* 2017; Smith *et al.,* 2022; Gárate-Escamila *et al.,* 2020). In berry species soil data, PC2 is primarily associated with hydrocarbons, suggesting these chemicals, though contributing to variance, have less explanatory power compared to PC1 variables (Lever *et al.,* 2017; Smith *et al.,* 2022; Gárate-Escamila *et al.,* 2020). This doesn't imply hydrocarbons are less important for soil quality, but they may be less decisive in differentiating samples compared to PC1 variables (Lever *et al.,* 2017; Smith *et al.,* 2022; Gárate-Escamila *et al.,* 2020). Key hydrocarbons in pin cherry soil include alkylated LMW (C0-C1 Dibenzothiophene) and HMW (C1-C2 Chrysene) PAHs, alongside parent HMW PAHs (Benz[a]anthracene, Benzo[a]pyrene, Benzo[g,h,i]perylene, Dibenzo[a,h]anthracene), with their total content noted (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). The strong correlation of both parent and alkylated PAHs within PC2, despite ring structure differences, suggests a shared source for these hydrocarbons (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). In blueberry soil, the main but secondary contributors are the total content of alkylated and parent PAHs, specific alkylated LMW PAH monomer (C1 Fluorene), and various HMW PAHs (Benz[a]anthracene, Benzo[a]pyrene,

Benzo[b]fluoranthene, Benzo[g,h,i]perylene, Benzo[k]fluoranthene, and Indeno[1,2,3-c,d]pyrene). Notably, in the OS region, PAHs are categorized into Petrogenic, Pyrogenic, and Diagenetic–biogenic sources (Harner *et al.,* 2018). Typically, HMW PAHs arise from pyrogenic sources like vehicular emissions and combustion, while LMW PAHs are mainly from petrogenic sources such as industrial oils (Kumar *et al.,* 2020; Benlaribi and Djebbar, 2020; Grmasha and Abdulameer, 2023; Balmer *et al.,* 2019). Alkylated PAHs are often highly associated with petroleum sources (Yang *et al.,* 2021; Yang *et al.,* 2014). The use of diagnostic tools like the pyrogenic index (PI) is invaluable in discerning the origins of these hydrocarbons (Yang *et al.,* 2021; Yang *et al.,* 2014). PI is calculated as the ratio of the sum of EPA priority parent PAHs to the sum of widely studied alkylated PAHs, including C0-C4 naphthalene, fluorenes, phenanthrenes, dibenzothiophenes, and chrysene (Yang *et al.,* 2021; Yang *et al.,* 2014). Data from pin cherry and blueberry soil samples across reclaimed sites, adjusted for detection limits, showed a PI value less than the threshold of 0.06, while samples from certain natural sites had a PI > 0.06 (Table 1a) (Yang *et al.,* 2021; Yang *et al.,* 2014). This suggests that hydrocarbons influencing reclaimed environments are predominantly originating from petrogenic sources, while natural soil likely have a dominant pyrogenic influence (Yang *et al.,* 2021; Yang *et al.,* 2014).

However, blueberry soil from sampling sites, particularly SS3, demonstrated a positive association with PC2 (Figure 9) (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). This association suggests that the presence of alkylated- and parent-PAHs, originating from mixed sources, particularly influences the hydrocarbon content of soils from the reclaimed site, making these hydrocarbons, especially those of petrogenic origin, more influential in these soils compared to their natural counterparts (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Similarly, pin cherry soil samples from SS2 show a positive correlation with PC2 (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013), indicating that hydrocarbons, likely from a

petrogenic source, have a more pronounced influence in the vicinity of pin cherry grown in SS2 soil compared to other selected sites (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Tailings sand, with its components of silt, clay, sand, water, and bitumen, is intermixed with petroleum-derived hydrocarbons and present in the soil cover of both SS2 and SS3 (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013; Cosia Land EPA, 2017). These findings imply that while these hydrocarbons in such reclaimed soil composition do not primarily alter soil quality variance, they still exert a significant secondary influence on the soil quality where these reclaimed berries are grown (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013).

PC3 and PC4 account for smaller variances than PC2, representing over 8% and 7% in pin cherry soil samples and 14% and 7% in blueberry soil samples, respectively (Figures 9 and 10). Their lower variance percentages indicate that the variables they represent, such as LMW APAHs (C2 Naphthalene and C2 Fluorene for PC3, and PC4, respectively) in pin cherry soil, and different APAHs (LMW C2-C4 Naphthalene and C2-C3 Phenanthrene; HMW C3 Chrysene) for PC3, and zinc for PC4 in blueberry soil, reflect less pronounced distinctions among the soil samples compared to the variables in PC1 and PC2 (Gárate-Escamila *et al.,* 2020). However, the correlation between these specific alkylated PAHs, suggests a shared source. While hydrocarbons are not the primary drivers of soil quality where these berries are grown, they remain influential, with a stronger impact than elements like zinc, especially in blueberry soil samples.

Soil samples from SS1 and RS1 tend positively towards PC3, with some samples from SS1 showing a less clear trend with PC4 (Figure 9) (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Similarly, certain samples from SS3, while not clearly aligned with PC3, display positive correlations with PC4 (Figure 10) (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). This pattern suggests that these hydrocarbons, significantly representing

these two components, enhance the concentrations of these factors in their respective areas, mainly the sampled reclaimed sites. However, given that PC3 and PC4 account for a lesser portion of the total variance compared to PC1 and PC2, their impact, while significant, is less dominant in determining the overall soil quality of these sites (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013).

2.) Drivers of Fruit Quality in Fort McMurray

In Figure 11, the variance in pin cherry fruit samples from sites SS1, SS2, and RS1 is primarily driven by APAHs. Specifically, C1-C4 alkylated homologues of Phenanthrene, Dibenzothiophene, Fluorene (notably, C4 Fluorene is only reported for pin cherry reclaimed sites), and Retene contribute significantly to the total APAHs (Kozhevnikov *et al.,* 2021). PC1 accounts for over 27% of the total variance, with individual variables like Retene and Total APAHs contributing variances of 51.4% and 74.4% (See Appendix equation 2), respectively. The parent forms of these APAHs are LMW, including Retene, which is an indicator of wildfires and significantly impacts the variance in pin cherry fruits (State Water Resources, 2017; Zhang *et al.,* 2022). Although LMW PAHs are typically linked to petroleum sources, their strong association with Retene suggests a primary origin from wood combustion in the pin cherry fruits (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). In contrast, in the blueberry fruit samples from sites SS3 and RS2, PAHs predominantly influence the variance, as shown in Figure 12 (Kozhevnikov *et al.,* 2021). PC1 explains 31.8% of the total variance, with individual PAH variables like Pyrene and Indeno[1,2,3-c,d]pyrene having variances of 95.5% and 97.8%. The diagnostic ratio of LMW to HMW PAHs (sum of LMW PAH concentrations divided by sum of HMW PAH concentrations) is 0.41 and 0.17 for RS2 and SS3, respectively. Ratios greater than 1 indicate petrogenic sources, while less than 1 suggest pyrogenic sources (Udofia *et al.,* 2021; Jamhari *et al.,* 2014). Thus, the

LMW to HMW ratios imply that the PAHs influencing blueberry fruits from these sites are likely derived significantly from pyrogenic components (Udofia *et al.,* 2021).

PAHs and their alkylated derivatives are not typically recognized for playing an essential role in plant growth and development (Molina and Segura, 2021). Yang *et al.* (2022) observed that low concentrations of pyrene in the soil (ranging from 5 to 45 mg/kg) positively influenced the growth of Chinese cabbage (Brassica campestris L.), with increases in root and shoot biomasses by 20-220% and 55-97%, respectively, compared to the control (Molina and Segura, 2021). However, at higher concentrations (405 mg/kg), plant growth was impeded, with reductions in root and shoot biomasses by 41-66% and 43-91%, respectively (Molina and Segura, 2021). This indicates that the impact of PAHs on plant growth is concentration-dependent (Molina and Segura, 2021). Alkylated PAHs are generally considered more toxic and persistent than their parent compounds, with a tendency to bioaccumulate due to their enhanced ability to traverse cell membranes and their increased hydrophobicity (Li *et al.,* 2022; Golzadeh *et al.,* 2021). LMW PAHs are more readily absorbed by plant roots and accumulate more in plants than HMW PAHs, owing to their lower Log p values (ranging from -1 to 4), resulting in higher stability in soil and lower volatility and degradability (Al-Nasir *et al.,* 2022). However, a higher prevalence of HMW PAHs in plants could indicate initially higher LMW PAH concentrations in the soil, making them more susceptible to removal from this medium, despite their higher Log p values (Al-Nasir *et al.,* 2022).

In this study, both pin cherry and blueberry soil samples exhibited higher total APAH concentrations than total PAH concentrations (after correcting for detection limits) (Tables 1a and 2a) (Molina and Segura, 2021). This indicates that APAHs are more prevalent in the sampled soil compared to PAHs (Molina and Segura, 2021). In all pin cherry fruits, the concentration of LMW APAHs (7-24 ng/g) surpassed that of HMW APAHs (0.7-2 ng/g) when corrected for detection

limits, despite the average concentration of total APAHs (7-23 ng/g) being greater than that of total PAHs (0.49 ng/g) (Molina and Segura, 2021) (Table 1b). This implies that APAHs accumulate to a larger extent in the pin cherry samples than PAHs and that the abundance of LMW APAHs exceeds that of HMW APAHs (Molina and Segura, 2021). This dominance of LMW APAHs largely contributes to the variance explained by PC1 (Molina and Segura, 2021). In contrast, while the detection limit corrected concentration of total APAHs (11-19 ng/g) in blueberry fruit samples was higher than that of total PAHs (0.6-3 ng/g), there was a more pronounced presence of HMW PAHs (0.4-2 ng/g) compared to LMW PAHs (0.2-0.4 ng/g) (Molina and Segura, 2021) (Table 2b). This suggests that, in blueberry fruits, while APAHs are more abundant than PAHs, HMW PAHs tend to accumulate more than LMW PAHs (Cui *et al.,* 2021; Al-Nasir *et al.,* 2022; Zelinkova *et al.,* 2015). A possible explanation is that the waxy surfaces of certain plants, including blueberries, can accumulate particle-bound HMW PAHs, primarily from the atmosphere via atmospheric deposition (Cui *et al.,* 2021; Al-Nasir *et al.,* 2022; Zelinkova *et al.,* 2015). Conversely, LMW PAHs often accumulate through adsorption from the soil surface (Molina and Segura, 2021). Correlation results in our study did not show any significantly strong associations between PAHs in the sampled fruits and soil (Tables 3a and 4-6). However, the PCA analysis underscores that PAHs (both HMW and LMW) are key influencers in blueberry samples (Molina and Segura, 2021). This suggests that even at low concentrations, PAHs, irrespective of their uptake route, exert considerable effects on blueberries, possibly due to APAHs' higher toxicity relative to PAHs (Molina and Segura, 2021). This might trigger oxidative stress, undermining the overall health of the blueberry plants (Molina and Segura, 2021).

Pin cherry fruit samples from SS1 clustered positively with PC1, suggesting that the fruit quality from these reclaimed sites is primarily influenced by LMW APAHs (Figure 11) (Zhao *et al.,* 2022). However, RS1 and SS2 fruit samples show opposing characteristics. In contrast, blueberry fruit

samples, specially from SS3 exhibit a negative association with PC1, implying that PAH variables have an inverse impact on fruit quality at this reclaimed site (Figure 12) (Rahman *et al.,* 2021). This demonstrates that APAHs are dominant positive drivers in these reclaimed pin cherries from SS1, while PAHs are more negative dominant drivers in the reclaimed blueberries from their sampled areas.

In addition to PC1, other Principal Components (PCs) in sampled pin cherry fruits prominently include micronutrients, macronutrients like Mg, metalloids (*i.e.,* As), TAC, and pH (PC2) (Figure 11) (Zhao *et al.,* 2022). They are followed by another antioxidant function indicator (TAA) and a specific APAH (C3 Phenanthrene) in PC3 and PC4 (Kozhevnikov *et al.,* 2021). This underlines the importance of analyzing these variables in pin cherry fruits, particularly their antioxidant capacity and activity (Zhao *et al.,* 2022). While these variables might be less impactful than those in PC1, they still significantly contribute to the overall variance. Research on antioxidant potential in pin cherries and related species is limited (Zhao *et al.,* 2022). However, a study by Li *et al.* (2008) showed that Chokecherry (*Prunus virginiana*), closely related to pin cherry, had high levels of Total Phenolic Content (TPC), Total Anthocyanin Content (TAnC), and TAC, even surpassing wild blueberries (*Vaccinium angustifolium*). This, coupled with the familial relationship between Chokecherry and pin cherry, suggests a strong antioxidant potential in pin cherries. This potential indicates a significant presence of antioxidants in pin cherries, likely affecting their overall quality, including nutrient content and properties like pH (Zhao *et al.,* 2022).

In the blueberry samples, PCs with lower variances than PC1 predominantly feature APAHs, including both HMW and LMW, with PC2 explaining 21.3% of the total variance (Figure 12) (Zhao *et al.,* 2022). This is followed by TEs (including micronutrient B, HMs, metalloids such as Cd, Pb, As, and other metals like Cr) and specific APAHs (C4 Chrysene and Phenanthrene), and

TPC, accounting for 13.4% and 8.6% of the variance for PC3 and PC4, respectively (Zhao *et al.,* 2022). The predominance of non-essential chemicals like Alkylated PAHs over TEs suggests their more dominant impact on blueberry fruit quality. The strong association of C4 Chrysene in blueberry fruits with soil APAHs (Table 5) implies soil-to-fruit influence and a possible interaction between APAHs and phenolics (Zhao *et al.,* 2022). This underscores the need to explore the relationship between toxic APAHs in fruits and soil and their impact on fruit quality. The correlation between specific fruit-derived APAHs and phenolics suggests a mitigating influence of phenolics against the oxidative stress induced by APAHs (Alwan, 2015; Nikzad and Parastar, 2021). However, the impact of these specific APAHs and TPC (including TEs) on overall fruit quality is not overwhelmingly significant, as indicated by their lower contribution to the total variance in PCs compared to PC4 (>10% for PC4 and >0.00% for PC1) (Tavakol and Wetzel, 2020). While PC1 captures the most variance overall, its specific contribution to APAHs and TPC is less than that of PC4, which captures more specific and orthogonal patterns (Tavakol and Wetzel, 2020).

Overall, the alignment of natural and reclaimed berry samples with PC2-PC4 is less specific and less distinct, contributing less to the overall variance of variables driving fruit quality in the AOSR (Rahman *et al.,* 2021). Monitoring pin cherries and blueberries in Fort McMurray is crucial, as their quality is significantly influenced by highly toxic and persistent hydrocarbons (Rahman *et al.,* 2021). In contrast, the impact of nutrients and health-promoting antioxidants on their fruit quality is comparatively lesser (Rahman *et al.,* 2021).

Factors driving berry harvested environment composition

Soil-specific Trace Elements (TEs) such as Cd, Pb, Cu, and Se, and properties like CEC, OM, Silt, Clay, K, N, and Moisture, predominantly influenced the variance (PC1) of the sampled pin cherry

environment, covering both fruits and soil (Figure 13A) (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). This was similar to the results when analyzing pin cherry's soil alone, with some differences like the inclusion of more TEs, as shown in Figure 9 (Kumar *et al.,* 2020; Benlaribi and Djebbar, 2020; Grmasha and Abdulameer, 2023; Balmer *et al.,* 2019; Molina and Segura, 2021; and Zhao *et al.,* 2022). However, when integrated with fruit samples, some soil variables that primarily shaped the total variance became less significant, particularly certain micronutrients (Co, Ni) and Heavy Metals (HMs) (Cr), yet soil TEs and properties remained dominant (Kozhevnikov *et al.,* 2021; State Water Resources Control Board, 2017; Zhao *et al.,* 2022). This illustrates the evolving influence of variables when fruits and soil are combined in environmental studies (Molina and Segura, 2021). The strong association of TEs in PC1 with the variance in pin cherry samples implies a common source, potentially anthropogenic, linked to activities like bitumen mining (Saintilan *et al.,* 2019). These elements, including copper, often found in liquid petroleum, suggest a strong interaction between TEs and soil physicochemical properties (Shotyk, 2022; Zhang *et al.,* 2022; Phillips-Smith *et al.,* 2017; Saintilan *et al.,* 2019). While this relationship was particularly noted in samples from SS2 and RS1, the PCA results for pin cherry soil samples showed a different pattern, with RS1 not being enriched in these TEs and properties (Figures 13A and 9A). The inclusion of RS1 suggests that similar soil-TE and property relationships exist between RS1 and SS2, indicating that integrating fruit variables can reveal interactions not apparent with a more limited set of variables. The data suggest that these primary influencing soil-derived TEs and properties are common in both SS2 and RS1 samples, implying that these soil characteristics significantly affect the environments where pin cherries grow in both types of sampled sites (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013).

In the pin cherry sampled environment, the patterns in variables with ascending components of the PCA were less distinct (Figure 13). However, soil-derived Retene and nutrients (Phosphorus),

captured in PC2, followed by soil-derived APAHs (represented in PC3 and PC4), positively influenced the overall variance in the sampled pin cherry environment, albeit to a lesser extent (Figures 13A and B). This pattern was similar to results from pin cherry soil samples alone, which identified both parent and alkylated hydrocarbons as secondary-minor influencers, contrasting with soil-derived APAHs' dominance when fruit variables were integrated (Figures 9 and 13; Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). This indicates that factors influencing pin cherry soil in isolation may not retain the same level of influence in a broader environmental context, where APAHs dominate (Sams *et al.,* 2022). This underscores the importance of these variables in understanding the broader environmental context of pin cherries (Sams *et al.,* 2022). Hence, variables that are dominant influencers in isolation may not exert the same influence when combined with other environmental components, emphasizing the need to incorporate diverse environmental mediums for a comprehensive understanding (Sams *et al.,* 2022). The characteristics in PC2 were more evident in sampled pin cherry soil from select areas of SS1 and RS1. However, APAHs, despite having a less dominant influence on the overall variance of the pin cherry environment and being less informative in site distinctions, seemed to align with the characteristics in SS2 samples. This suggests that while there are no distinct patterns differentiating the environments of certain reclaimed and natural pin cherry grown sites, soil-derived APAHs, even as minor influencers, play a more significant role in shaping the reclaimed pin cherry sampled environments (Tommasi *et al.,* 2023).

In the blueberry samples, the primary environmental drivers were soil-derived TEs and properties, with a few exceptions like specific APAHs (C0-C1 Dibenzothiophene, C1-C2 Chrysene), as shown in PC1 of Figure 14A. While TEs and properties dominate in isolated blueberry soil samples, integrating fruit samples reveal soil-derived APAHs also as key components shaping the overall environment. This indicates that the influence of TEs and properties is stronger in isolation,

but when diverse mediums are incorporated, APAHs from the soil emerge as significant influencers (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). This highlights the evolving impact on environmental composition with the inclusion of more factors like soil and fruits. The pattern underscores the critical role of soil-derived variables, including alkylated PAHs, in shaping the sampled blueberry environments (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Despite standardizing for OM in the soil, alkylated PAHs remain influential, suggesting their significant environmental impact regardless of soil OM content. This is concerning as APAHs are persistent environmental chemicals. The negative association of retene, sand, and pH with these primary variables implies an inverse relationship, where they oppose the positive influencers. Although wildfires are a likely source of retene in this setting, its presence, along with coarse-textured (sand) and acidic (pH) soil conditions, does not positively affect the blueberry environment influenced by soil-TEs, properties, and some APAHs (Reisen and Arey, 2002). This trend was consistent in sampled environments from the reclaimed site (SS3) but opposite in the natural site. Therefore, monitoring efforts should focus on these soil-derived variables, especially APAHs, in Syncrude OS reclaimed sites in Fort McMurray where blueberries are grown.

Further analysis of additional Principal Components (PC2 of Figure 14A) reveals that all parent PAHs in sampled blueberry fruits significantly influence their overall composition. These non-alkylated PAHs, predominantly of pyrogenic origin (diagnostic ratio < 1), secondarily influence the blueberry environment (Udofia *et al.,* 2021; Zhao *et al.,* 2022; State Water Resources Control Board, 2017). Additional PCs (PC4), though less informative, indicate that certain LMW APAHs (C2-C3 Phenanthrene), including Retene, have a less dominant influence. However, their strong association with Retene suggests a shared, likely pyrogenic, origin. This indicates that alkylated hydrocarbons from pyrogenic sources exert varying influences on the sampled blueberries.

Monitoring and management of such sources in Fort McMurray, where blueberries are cultivated, is crucial (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013). Continuous assessment of PAHs in both soil and blueberry samples is essential to understand temporal trends and identify potential sources (Tommasi *et al.,* 2023). Spatial distinctions among sampled sites became less clear, offering reduced explanations of the variances (Tommasi *et al.,* 2023). However, a subtle trend was observed: in some reclaimed site areas, the presence of hydrocarbons, particularly PAHs, was evident in blueberry samples (Tommasi *et al.,* 2023). Although these PAHs play a less dominant role in shaping the overall variance in the reclaimed conditions of Fort McMurray, their presence is notable. Therefore, ongoing monitoring in the reclaimed environments of Fort McMurray is vital to ensure the health of blueberries, influenced by hydrocarbons from both pyrogenic and petrogenic sources and not negatively affect the overall quality of the blueberry environment (Tommasi *et al.,* 2023).

Environmental factors influencing health metrics in berries

To assess the influence of environmental variables on the concentration of antioxidants (TAA, TAC, TPC, TAnC, and Vitamin C) in the fruits from this study, we conducted a PCR. We considered the four PCs described in this study because they capture a significant and insightful portion of the variance in the data.

For the pin cherry samples, TAA (measuring the capacity to neutralize free radicals) and TAC (measuring the ability to prevent or delay oxidative damage) were significantly affected by environmental variables, as shown in Figure 15 (Gramza-Michałowska *et al.,* 2019; Dong *et al.,* 2022; Ali and Younas, 2021). The regression model indicated that the predictor variables, representing the four PCs, accounted for 24% and 39% of the variance in TAA and TAC concentrations in pin cherry samples, respectively (Appendix Table 21a) (Ali and Younas, 2021).

Notably, soil-derived retene and Phosphorus (PC2), as secondary influencers, positively impacted TAC variance (Beta = 0.06), while less dominant variables (PC4) negatively influenced TAA variance (Beta = -0.02) (Figure 15) (Ali and Younas, 2021). These correlations between soil-specific retene and Phosphorus with TAC were evident in pin cherries from specific areas of a reclaimed site (SS1) and the natural site (Figure 13) (Ali and Younas, 2021). Conversely, the negative impact on TAA showed limited spatial variation (Figure 13) (Ali and Younas, 2021). This suggests that, regardless of the magnitude of environmental influence, including both secondary influencers like wildfire markers (Retene) and certain soil nutrients, as well as minor influencers, can impact the antioxidant functions in these sampled pin cherries. Specifically, TAC is influenced by secondary environmental drivers, broadly affecting the antioxidant content, while TAA is more sensitive to specific changes with less dominant influence on the overall pin cherry environment (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013; Ali and Younas, 2021). Overall, this interaction is notable in OS surrounded environments, regardless of site types (Shange *et al.,* 2012; Ambade *et al.,* 2021; Piazzalunga *et al.,* 2013; Ali and Younas, 2021). However, these variables explained only 21% and 30% of the variance in TAA and TAC levels, respectively (Figure 15) (Ali and Younas, 2021). R^2 values below 0.6 are common in ecological research due to the myriad of influencing factors (Ali and Younas, 2021). An R^2 value of 0.3 or less, however, indicates a weak model fit, possibly due to our limited sample size (< 30 pin cherry samples) or unaccounted influential variables (Ali and Younas, 2021). Unmeasured factors may account for the large portion of unexplained variance (>70%) (Ali and Younas, 2021). This highlights the necessity to further explore the complex interactions affecting the antioxidant profile of pin cherries. Regular monitoring of their nutritional quality in different site types in the OS region is crucial, especially considering the influence of environmental variables like hydrocarbons on antioxidants (Ali and Younas, 2021).

In the blueberry samples, only TPC displayed a significant regression model (Figure 16) with its associated PCs ($p < 0.05$). Within this model, primarily soil derived TEs, physicochemical properties and specific APAHs (both HMW and LMW), which were the primary drivers of the overall sampled blueberry environment (PC1) and the less dominant environmental drivers of both fruits and the soil of sampled blueberries which did not show distinctly strong associations (PC3), exerted a significantly strong negative (Beta = -0.19) followed by positive (Beta = 0.22), respectively influence on TPC concentration (Ali and Younas, 2021; Sams *et al.,* 2022). This suggests an inverse relationship between dominant blueberry environmental drivers in Fort McMurray and the phenolic concentration in these samples, while this relationship becomes more positive with both fruit and soil attributes in this environment that are minor influencers in shaping their environment quality (*i.e.,* as the level of these environmental variables rises it positively influence the level of phenolic content in these blueberries) (Ali and Younas, 2021; Sams *et al.,* 2022). The relationship with dominant drivers was particularly evident in SS3 samples, and an opposite trend was observed in RS2 samples, while site-specific variability distinguishing this relationship was less pronounced with the less dominant drivers (Figure 14) (Ali and Younas, 2021; Sams *et al.,* 2022). This implies that primary driving environmental conditions, which are the soil conditions in the reclaimed blueberry sites, might negatively impact the phenolic content in blueberries, whereas natural sites could produce the opposite effect, while environmental conditions, even if they are minor influencers within the sampled areas of Fort McMurray regardless of the site type are more positive in influencing the phenolic content in blueberries grown in this environment (Ali and Younas, 2021; Sams *et al.,* 2022). Thus, monitoring sites, particularly reclaimed ones in Fort McMurray is essential for blueberry health (Ali and Younas, 2021; Sams *et al.,* 2022). Notably, environmental drivers that differ by their magnitude of impact included in the regression models accounted for 37% (dominant drivers) and 24% (less dominant drivers) of the variance in TPC (Figure 16), suggesting weak-moderate model fits within an

ecological framework, hence it is important to explore other unmeasured factors that could be impacting the phenolic content in these berries (Ali and Younas, 2021; Sams *et al.,* 2022).

Overall, our findings indicate that in both berry types from sampled Fort McMurray sites, the concentration of specific antioxidants and the plant's capacity to defend against oxidative stress are primarily and strongly influenced by soil TEs and their properties, but also specific hydrocarbons (mainly alkylated) (Ali and Younas, 2021; Sams *et al.,* 2022). For pin cherries, the influence primarily comes from specific variables, whereas for blueberries it is influenced predominately by a multitude of different soil derived chemicals and properties (Ali and Younas, 2021; Sams *et al.,* 2022). Patterns of both positive and negative associations between soil variables and antioxidants in both these berries raises concerns about the quality of these berries grown in Fort McMurray, as antioxidants can both be enhanced or reduced under stress conditions (Ali and Younas, 2021; Sams *et al.,* 2022). Although this trend was evident in both reclaimed and natural sampled sites, it was more pronounced in certain OS reclaimed berries, particularly blueberries from the sampled Syncrude sites (Ali and Younas, 2021; Sams *et al.,* 2022). Therefore, OS companies should prioritize monitoring the antioxidants when assessing berry health in their sites (Ali and Younas, 2021; Sams *et al.,* 2022). It is essential to continually monitor the nutritional quality of these berries, given that their composition seems to be influenced by various concerning chemicals (Ali and Younas, 2021; Sams *et al.,* 2022). This is true even if the chemical concentrations in the plants and soil remain below their relevant guideline limits (there is no established threshold concentration for individual APAHs and total hydrocarbons currently) (Ali and Younas, 2021; Sams *et al.,* 2022). Moreover, our detailed analysis of the interplay among environmental variables reveals that while some variables might seem influential or opposite in isolation, their significance can either emerge or diminish when considered amidst a multitude of environmental factors (Ali and Younas, 2021; Sams *et al.,* 2022).

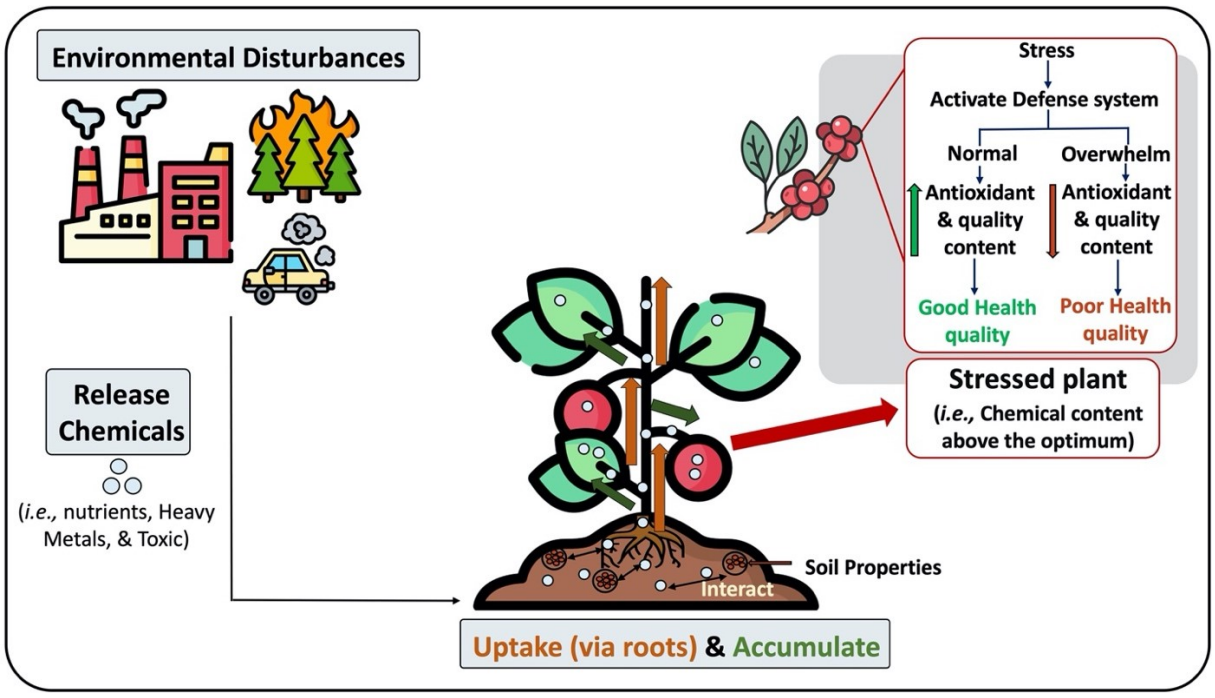

Figure 17: Pictorial Summary of the results (created by Chathumi De Silva)

CONCLUSION

In conclusion, we observed that the concentrations of hydrocarbons (PAHs and APAHs) were generally higher in samples from reclaimed sites than in those from natural sites, higher in blueberries than in pin cherries (with the exception of blueberries from reclaimed sites), and higher in soil than in fruits. Among all the chemicals assessed in soil and fruits, only the levels of Cu and Fe in fruits from all sites exceeded their respective limits.

In the sampled fruits, specific alkyls of Chrysene in pin cherries and blueberries demonstrated a strong association ($R < -0.8$ and > 0.8; $p < 0.05$) with different TEs and alkylated PAHs in their corresponding soils (only APAHs in pin cherry soil), accounting for majority of the variance in the fruit.

For the soil samples from pin cherries, especially from the reclaimed site (SS2), there was a dominant influence from both soil derived TEs and properties (PC1), likely originating from anthropogenic activities. In the case of blueberry soil samples, mainly from the reclaimed site, the key factors were TEs and soil properties with retene (a wildfire biomarker), sand, and pH exerting an inverse influence (PC1). For both berries, PAHs and APAHs impacted the soil composition variance, but they acted as either secondary (PC2) or lesser influencers (PC3-PC4). Spatial variation was less clear with non-primary driver variables with exceptions (secondary influence more evident in SS2). In pin cherry fruit samples, mainly from SS1, APAHs (LMW) were the primary influence, accounting for 28% of the variance (PC1). In contrast, in blueberry fruit samples, mainly from reclaimed sites, all PAHs impacted 32% of the variance (PC1), likely influenced by pyrogenic components (ratio < 1).

Considering both samples, the pin cherry environment, predominantly in SS2 and the natural site, was majorly influenced by soil-TEs and -properties. In contrast, the blueberry environment, mainly in SS3, was shaped primarily by soil-derived TEs, properties, and certain alkylated PAHs,

accounting for 29% of the variance in the berry-growing environments. However, hydrocarbons in the sampled pin cherry (specific APAHs) and blueberry (mainly PAHs) still exerted an influence, although their impact was less dominant.

Hence, our preliminary study's significant finding is that concerning hydrocarbons, particularly prevalent in reclaimed sites, have a less influential but still significant impact on overall quality. Soil properties strongly influence the primary driving soil TEs, while most hydrocarbon chemicals significantly influence each other. In the sampled pin cherries, regardless of land type, TAC and TAA showed both negative and positive trends, influenced by secondary soil factors such as retene and Phosphorus and other minimal environmental drivers, respectively accounting for <30% of their variance. Meanwhile, TPC in blueberries from site SS3 was affected by soil derived TEs, properties, and some APAHs (primary environmental drivers), alongside less influential variables of both fruits and soil, accounting for the majority of the variance. Predominantly, the soil conditions in environments where mainly reclaimed berries grow in sampled Fort McMurray significantly influence nutritional quality from a health-for-consumption context. This underscores the need for further site monitoring.

LIMITATIONS AND FUTURE DIRECTIONS

During the sample collection period, limited berry species exhibited fully developed fruits, leading to a reduced sample size and limited statistical power for comparisons between fruit and soil attributes. This baseline study suggests that larger sample sizes would offer better insights into spatial and temporal relationships, particularly regarding the differing influences on antioxidant content between OS reclaimed and natural Fort McMurray sites.

Environmental conditions varied between and within reclaimed sites, affecting sample consistency. Future research should either sample reclaimed areas with uniform conditions or

identify reclamation materials responsible for, such as elevated hydrocarbon content. Adjusting reclamation strategies could enhance the nutritional value of berries in these environments.

This study captured only a single point within the growing season of these berries. Since ripening rates vary due to environmental factors, capturing a single growth phase may not comprehensively represent how environmental shifts affect antioxidant content. Future research could gather data throughout the season, detecting trends in chemicals and antioxidant accumulation.

Finally, antioxidants, while essential for health and indicative of fruit quality, represent only one component of nutritional value. Comprehensive assessments should also consider other phytochemicals. Limited existing data on pin cherry's nutritional composition makes statistical comparisons challenging between berries from reclaimed and natural settings. To truly understand their nutritional value, more extensive data on pin cherry is vital.

This study is limited by its cross-sectional design. All results observed simply suggest that there is a relationship between the environmental attributes and the nutritional properties of the berries. To confirm what the results of this study imply, future controlled experiments with a defined dose range of PAH is needed to show the cause-effect relationship.

SIGNIFICANCE

This study is of considerable importance for several reasons. First, it delves into the environmental factors influencing the quality of fruit-producing plants like pin cherries and blueberries. These plants, with their rich indigenous cultural significance in Northern Alberta, are integral to the region. Given that Northern Alberta frequently faces various environmental disturbances, understanding factors that influence essential health components, such as antioxidants, is crucial. By doing so, stakeholders, including the locals and the Indigenous communities can better

safeguard the quality of these widely consumed fruits. This understanding can also inform and refine existing environmental management and monitoring strategies, ensuring that berries from this region are both safe and nutritious to consume.

Second, the research offers insights into the complex dynamics between soil and fruit quality parameters in the Fort McMurray region. This exploration will shed light on how these variables interact within the different landscapes—both reclaimed and natural—found in the area.

Third, this study sets the groundwork for further research. It offers a solid foundation from which subsequent research can delve deeper into the predominant environmental factors affecting plant nutritional quality. Such foundational work also paves the way for comparative studies on the nutritional quality across various terrains within Alberta.

Finally, the insights garnered from this research can inform stakeholders and rights holders, guiding potential policy refinements or shaping future research directions. By focusing on vital health metrics, alongside toxicological and nutritional components, this study paints a comprehensive picture of the ecosystem health in Fort McMurray. Future researchers can use this as a basis to examine temporal shifts, determining if and how the factors influencing soil and fruit quality in the region evolve over time. Such knowledge is vital in pinpointing activities driving these changes. In sum, this study's exploratory approach lays the foundation for more detailed inquiries, guiding sustainable land management and deepening our understanding of ecosystem relationships.

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APPENDIX

Table 1: Raw data for TEs, hydrocarbons, and fruit quality variables in blueberry fruits

Sample ID	K1	K2	K3	K4	K5	K6	K6	N1	N2 bare hands	N2 bare hands	N2 bare hands + deet	N2 gloves	N4 bare hands	N4 bare hands + deet	N4 gloves
Site Name	Kingfisher	Kingfisher	Kingfisher	Kingfisher	Kingfisher	Kingfisher	Kingfisher	Fort Chipewyan	Fort Chipewyan	Fort Chipewyan	Fort Chipewyan	Fort Chipewyan	Fort Chipewyan	Fort Chipewyan	Fort Chipewyan
Site	SS3	SS3	SS3	SS3	SS3	SS3	SS3	RS2	RS2	RS2	RS2	RS2	RS2	RS2	RS2
Site Type	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural
C1 Chrysene	0.5051507 5	1.0050344 3	0.23930552	0.27469432	0.17028 6339	0.16268 6658	0.32780 8723	0.26436 1951	0.30080 4766	0.44303 6291	-0.048202064	0.31084 4563	0.33408 9745	0.75155052	0.01444 2171
C1 Dibenzothiophene	0.0517766 8	0.9278945 8	0.03114 9545	0.23950 0201	0.09984 5525	-0.1123 21851	0.18482 4139	-0.0732 59013	0.09847 7605	0.12180 3149	-0.073259013	0.06077 4007	-0.0732 59013	0.254164018	0.06015 3691
C1 Fluorene	-0.226 9528	1.5109633 2	0.04102 2829	0.03674 2597	-0.0953 80406	-0.3762 79247	-0.0886 93383	-0.3659 82175	0.10917 1904	0.22717 6065	-0.365982175	-0.3659 82175	-0.3659 82175	0.43047499	-0.3659 82175
C2 Chrysene	1.7501850 1	1.3969291 7	1.88470 3115	1.06935 2535	0.65922 4996	0.67912 1181	0.98604 0815	1.44084 314	0.30337 0003	0.56850 5017	0.511918525	0.35358 6186	0.81122 0113	1.787212275	0.07845 5461
C2 Dibenzothiophene	0.1114517 4	3.3086151 4	0.09439 9513	0.72898 2679	0.44951 4482	-0.2805 17224	0.48960 6141	-0.0958 91069	0.47291 5877	0.50607 5252	-0.095891069	0.23649 2191	0.03906 8378	1.424830408	0.36855 3815

C2 Fluorene	-0.1330861	1.5498253 1	0.1101 09119	0.1390 37489	0.1936 31038	-0.2258 29598	0.0958 06021	-0.2182 33345	0.2641 03524	0.2780 02442	0.0094299 35	0.1431 89643	0.0051 92707	0.5349143 45	0.1160 30124
C2 Naphthalene	0.977 59958	0.857 52287	-1.6120 99525	-0.3309 63742	0.6354 53404	1.6975 37037	3.5733 82604	2.1262 65111	8.1992 61917	15.348 77692	0.2736255 08	0.3521 46165	-0.1610 02757	2.6889134 4	-0.1576 76698
C2 Phenanthrene	3.442 95956	5.312 44183	0.6110 9898	0.2964 05046	0.3930 24169	0.2495 53779	0.2481 50874	0.1873 56232	0.4224 25912	0.8781 09513	0.2997237 49	1.0371 34113	0.5230 90195	1.1215418 36	0.8844 81154
C3 Chrysene	0.039 08492	0.033 20815	0.1355 38052	0.0002 83238	-0.0116 51496	-0.0189 82783	-0.0013 32165	0.1587 98714	-0.0292 64612	0.0094 03627	0.1438420 85	-0.0144 27031	0.2424 31541	0.0428098 44	0.0106 12809
C3 Dibenzothiophene	0.133 74858	3.614 88375	0.1226 31168	0.7505 46035	0.1529 71428	-0.1623 85932	0.4432 94006	-0.0137 27868	0.9068 19364	0.7497 29201	-0.0137278 68	0.6001 58396	0.0534 26601	1.6118222 81	0.4033 91213
C3 Fluorene	-0.697 499	2.398 31615	-0.6974 99046	0.1138 23712	0.6362 168	-0.7522 72326	-0.1356 15287	-0.5466 05405	0.1807 57156	0.3481 64494	-0.5466054 05	0.1459 22397	-0.5466 05405	1.0205935 69	0.0803 41211
C3 Naphthalene	0.700 14256	0.948 08274	-0.8347 55216	-0.4684 27501	0.0520 28042	0.4922 85774	-0.0395 72228	-0.0218 93747	0.1383 50255	0.5849 79874	-0.7338684 94	-0.0432 97324	-0.5554 63143	0.1591214 17	-0.3008 91418
C3 Phenanthrene	3.821 87924	7.469 78058	-0.0279 9224	2.4809 1371	1.1066 7095	1.5527 19122	1.4324 73757	0.0145 0237	0.8709 46316	1.2557 67984	-0.3382603 86	1.7088 4465	0.7146 75916	1.6154918 55	0.5002 55365
C4 Chrysene	0.013 01129	0	0	0	-0.0070 26595	-0.0097 17048	-0.0097 53714	0.0959 50614	0	0	0	0	0	0	0

C4 Dibenzothiophene	0.1931407	11.881176	-0.664440836	0.732896086	0.537765763	-0.664440836	1.741520503	0.300606527	3.213643478	3.430763637	0.00272	2.403597955	0.00272	6.699519362	0.112397519
C4 Fluorene	-0.6577044	1.1785419 1	-0.657704433	-0.657704433	0.236632528	-0.702754176	-0.21091714	-0.536470335	-0.536470335	0.132416969	-0.536470335	0.040966745	-0.536470335	0.357733226	-0.536470335
C4 Naphthalene (Butyl)	0.1713880 6	0.7673969 7	-0.126035811	-0.115298819	-0.042624561	0.070160707	0.037794527	-0.056688607	0.014095578	0.143449332	-0.141114426	0.056856367	-0.088234803	0.096607729	-0.039756557
C4 Phenanthrene	0.9007588 1	2.1996946 3	0.028359635	0.070500685	0.022795508	0.013575593	0.045909919	-0.054917457	0.609254852	1.051163397	0.033374863	0.844173298	0.096301539	0.609647395	0.168386354
Dibenzothiophene	0.0047553 9	0.3460436 2	-0.094684725	0.094581486	0.018964315	-0.094684725	0.052478015	-0.054116885	0.048312084	0.057829686	-0.054116885	0.037488866	-0.054116885	0.087190237	0.02342075
Retene	0.1711153 9	0.3780138 5	-0.066426177	-0.050933694	0.117136237	0.020947772	0.032257821	0.079309525	0.267825692	0.361328288	-0.026117922	0.174876065	-0.026117922	0.179133928	-0.026117922
Acenaphthene	0.6094367 5	-0.04955112	-0.660383296	-0.418433966	-0.074364762	-0.248279484	-0.088329629	-0.202327717	-0.619696714	-0.725800834	-0.714749048	-0.719510897	-0.710613963	-0.079448985	-0.571498585
Acenapthylene	0.5762572 3	-0.0120126	-0.120591961	-0.111876421	-0.011186477	0.028470216	0.127592789	0.12569547	-0.055014227	-0.04325191	-0.111350232	-0.073006178	-0.120924611	-0.008557476	-0.113209294
Anthracene	0.3187220 2	-0.007817	-0.070472943	-0.071460439	-0.023408708	-0.015214299	0.04836602	-0.009244852	-0.081728087	-0.078153097	-0.077900692	-0.079733114	-0.07799465	-0.012026961	-0.078649992

Benz[a]anthracene	1.2978923 2	0.0516522 3	-0.076807957	-0.054159091	0.010506542	0.049513186	0.06469869	0.014838855	-0.102457686	-0.103215767	-0.121677954	-0.079565719	-0.113135492	0.021610206	-0.117748529
Benzo[a]pyrene	1.4831911 2	0.0561100 1	-0.020099045	-0.032471442	0.022929652	0.041779396	0.090461985	0.013906042	-0.097886338	-0.098188794	-0.063203426	-0.104339616	-0.062322681	-0.016282729	-0.083626114
Benzo[b]fluoranthene	1.5872990 6	0.0287361 9	-0.063163018	-0.084599572	0.001008608	0.057074051	0.000642663	0.004842559	-0.061098588	-0.069506674	-0.110593438	-0.109611367	-0.092937 68	0.018574643	-0.114537063
Benzo[g,h,i]perylene	1.3147499	0.0172266 8	-0.052781435	-0.059560509	0.011394 25	0.052315981	0.034093817	-0.001208916	-0.095648978	-0.109465164	-0.093425574	-0.113844373	-0.094034 62	0.003347711	-0.109251142
Benzo[k]fluoranthene	1.5345891 7	-5.911E-06	-0.086569819	-0.099102 1	-0.014606 47	0.029935745	0.002096183	-0.007189231	-0.070951471	-0.085276867	-0.115116689	-0.113756367	-0.103710 7	0.008450164	-0.117438658
Dibenzo[a,h]anthracene	1.2852814 4	-0.06596 69	-0.155408837	-0.150057471	-0.023890851	0.005145098	-0.009483533	-0.040829717	-0.167154063	-0.162377884	-0.162367727	-0.180428831	-0.165913242	-0.057784233	-0.176256283
Fluoranthene	1.1744746 6	0.0211596 3	-0.409010655	-0.432556221	-0.017607603	-0.020057443	-0.041192924	0.002808525	-0.395538204	-0.411033957	-0.437722 76	-0.402645884	-0.437938658	0.001538272	-0.420612434
Indeno[1,2,3-c,d]pyrene	1.4398452	-0.018 3311	-0.133992811	-0.132237005	-0.029712832	-0.006122858	-0.031326722	-0.030981593	-0.127974125	-0.145121515	-0.160805095	-0.143027041	-0.119567424	0.009806052	-0.161291238
Pyrene	1.2752970 9	0.1637288 4	-0.407031444	-0.424196828	0.036230378	0.062839709	0.051665451	0.054712991	-0.399537232	-0.406375269	-0.458670202	-0.39416425	-0.467769799	0.108696837	-0.458444545

Arsenic	0.0045	0.0055	0.0067	0.0076	0.0011	<MDL	<MDL	0.0042	0.002	0.002	0.0087	0.0026	0.0013	0.0015	0.0056
Boron	2.1	2	2	2.3	0.93	1.2	1.2	2.1	1.3	1.3	1.1	1.2	1.5	1.8	1.7
Cadmium	0.0029	0.002	0.002	0.0051	<MDL	<MDL	<MDL	0.0018	<MDL	<MDL	<MDL	<MDL	<MDL	0.0013	0.0023
Chromium	0.015	0.024	0.017	0.18	0.016	0.013	0.013	0.016	0.015	0.015	0.012	0.02	0.016	0.04	0.017
Cobalt	0.012	0.014	0.011	0.014	0.0014	0.0027	0.0027	0.0097	0.0045	0.0045	0.00054	0.0045	0.0022	0.003	0.0084
Copper	0.78	0.7	0.77	1.2	0.65	0.69	0.69	0.8	0.75	0.75	0.46	0.73	0.56	0.72	0.8
Iron	5.3	7.8	6.9	12	8.9	6.9	6.9	5.7	16	16	3.4	25	8.6	9	8.5
Lead	<MDL	0.003	<MDL	0.013	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0023	<MDL	0.0024	0.0024
Magnesium	100	100	110	110	89	98	98	90	84	84	51	83	76	87	90
Mercury	0.00018	0.00023	0.00016	0.00048	0.0003	0.00033	0.00033	0.0002	0.00018	0.00018	0.00028	0.00021	0.00033	0.00037	0.00024
Molybdenum	0.0023	0.0024	0.0021	0.0055	0.017	0.033	0.033	0.0024	0.09	0.09	0.0048	0.077	0.031	0.041	0.0035
Nickel	0.11	0.1	0.073	0.16	0.12	0.13	0.13	0.096	0.099	0.099	0.031	0.11	0.11	0.14	0.081
Selenium	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Zinc	2	2	2	3.8	1.4	1.8	1.8	2.2	1.7	1.7	0.71	1.6	1.4	1.8	2
TAnC	1.16	6.20	11.26	17.43	3.78	5.63	5.63	12.32	15.17	16.69	16.69	10.97	5.84	40.64	20.68
TAA	21.22	44.80	56.10	54.87	30.71	30.33	30.33	41.57	57.26	56.10	56.10	49.04	33.32	63.88	55.45
TAC	6.68	4.00	5.79	4.20	5.32	10.92	10.92	6.12	8.64	7.73	7.73	6.24	6.94	7.06	5.86

TPC	8.35	11.03	9.53	10.52	7.97	8.72	8.72	11.93	11.81	11.53	11.53	9.63	10.71	14.75	11.92
VitaminC	148.73	92.65	114.25	155.24	94.98	94.36	94.36	94.70	161.72	132.53	132.53	107.73	105.10	149.68	88.66
FruitpH	3.38	3.38	3.30	3.27	3.39	3.38	3.38	3.32	3.23	3.35	3.35	3.36	3.48	3.46	3.32
WaterContent	0.34	0.36	0.36	0.36	0.39	0.36	0.36	0.36	0.36	0.37	0.37	0.37	0.40	0.37	0.37

Table 2: Raw data for TEs, hydrocarbons, and properties in blueberry soil

Sample ID	K1	K2	K3	K4	K4	K5	K6	N1	N2	N4
Site Name	Kingfisher	Kingfisher	Kingfisher	Kingfisher	Kingfisher	Kingfisher	Kingfisher	Fort Chipewyan	Fort Chipewyan	Fort Chipewyan
Site	SS3	SS3	SS3	SS3	SS3	SS3	SS3	RS2	RS2	RS2
Site Type	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Natural	Natural	Natural
C1 Dibenzothiophene	28.828	54.247	31.138	52.107	22.95	29.83	13.927	0.619	2.555	0.056
C1 Fluorene	4.628	10.14	7.777	4.91	3.403	4.506	1.597	0.846	0.619	-0.601743718
C2 Dibenzothiophene	48.013	66.337	46.449	71.861	29.204	52.301	27.848	11.479	14.762	5.875
C2 Fluorene	25.98	35.366	33.769	39.946	18.85	23.73	14.474	7.933	19.144	2.39
C3 Dibenzothiophene	34.207	31.696	31.154	49.297	19.452	44.492	17.409	4.175	8.24	5.127
C3 Fluorene	59.116	103.811	60.73	110.305	52.523	54.939	37.595	16.603	35.881	3.859
C4 Dibenzothiophene	279.048	163.5	213.516	372.945	151.605	264.153	132.619	58.61	68.006	21.92

C4 Fluorene	35.678	36.36	40.847	51.972	24.481	36.957	20.77	9.3	20.695	3.096
Dibenzothiophene	8.257	11.257	12.551	8.653	6.454	7.763	4.478	0.234	0.247	0.075
C1 Chrysene	107.403238	396.942176	182.455274	174.488213	77.7722936	72.223869	77.4783731	4.15307429	13.1357439	4.43099079
C2 Chrysene	309.392936	1308.65191	641.135233	883.767772	371.564618	308.768439	367.491229	17.1294318	42.1828418	12.5019489
C2 Naphthalene	27.4725379	283.051735	32.2369906	70.3045182	29.0885924	24.5302378	27.7822064	12.1826224	10.0186902	13.2738133
C2 Phenanthrene	39.604490 8	214.202689	82.526697 1	104.367708	52.484634 9	35.538542 4	41.396669 7	5.38310666	16.1282271	4.5174221
C3 Chrysene	16.216269 1	118.490774	34.392747 4	41.677484 2	21.267772 3	20.668657 8	16.485180 1	3.41001589	4.37040237	5.65440456
C3 Naphthalene	17.436857 4	137.70928	30.462784 4	45.476226 5	24.122357 1	14.840684 5	18.436353 4	7.30871479	12.0674885	5.18783706
C3 Phenanthrene	52.288675 2	238.62153 3	88.708824 1	136.57096	65.373581 4	42.260557 3	48.653218 9	9.04860456	21.357269	8.41728577
C4 Chrysene	5.8713170 4	55.754685 8	20.268426	17.336496 4	10.098587	12.454572 8	7.7146548 8	3.65696431	4.99094299	5.10472351
C4 Naphthalene (Butyl)	22.857842 4	155.86365 7	28.144848 7	42.614067 2	19.819319 7	14.443079 8	19.711555	6.27251651	11.4690525	3.99101178
C4 Phenanthrene	34.935073 5	168.50001 5	57.712271 5	124.65517 5	52.351317 4	31.471599 6	36.411367 6	15.6797056	29.0273898	15.1053404
Retene	6.8442970 5	51.770990 2	11.537042 6	30.108619 4	27.503398 7	10.877246 6	12.524551	9.371265	21.5120792	7.21905678

Acenapthene	1.11011415	1.8562252 8	1.1343908 6	1.2415791 9	1.1574197 9	1.2460260 9	1.0582635 3	2.00546953	0.24494573	0.88455095
Acenapthylene	1.46677231	2.44723641	1.2817747 2	2.0704369 3	1.4441530 4	1.5547102 1	1.3542323 8	2.64399914	0.28962752	1.18203748
Anthracene	3.71851397	5.03078869	6.1874348 4	7.2296493 3	4.7550846 5	5.1191102 7	4.3143029 8	5.43527422	0.61615761	-0.002026049
Benz[a]anthracene	13.586437 5	14.893298 5	21.182134 2	22.539038	16.060441 6	17.289949 1	14.287154 6	16.0907496	0.77660684	-0.081672951
Benzo[a]pyrene	15.707040 1	25.507827 8	26.913533 7	30.145138 7	16.751293 9	18.033689 6	17.602303 8	27.5587084	0.37696645	0.32062546
Benzo[b]fluoranthene	11.063733 4	9.4294285 8	13.055475 1	16.020869	11.199329 9	12.056694 9	10.467619	10.1875736	0.47956963	0.29306467
Benzo[g,h,i]perylene	13.654901 1	14.102062	20.498830 4	21.592025	14.270619	15.363106 6	14.168871	15.2358961	0.30260203	0.1905566
Benzo[k]fluoranthene	4.13163424	3.9444376	7.1848564	7.7001495 9	4.6352710 6	4.9901243 4	4.3673503 5	4.26157831	0.39567666	0.0973385
Dibenzo[a,h]anthracene	5.76187335	5.61953779	8.7541020 6	8.7245560 7	6.1905945 7	6.6645156 9	6.4020044 4	6.07135992	-0.017850415	0.00172202
Fluoranthene	5.56088658	8.34731287	8.5417010 6	10.650835 6	9.0311649 6	9.7225460 1	8.6637694 5	9.0184536	2.77538153	0.75015854
Indeno[1,2,3-c,d]pyrene	4.94541783	5.32437177	6.8513092 5	7.4383666 1	5.2105555 9	5.6094498	5.4313103 3	5.75246197	0.24332085	0.1321493
Pyrene	16.858155 4	20.804891 4	31.665679 1	27.609140 9	20.656670 5	22.238042 4	23.037117 6	22.4776465	4.23671274	1.1723783
Arsenic	1.2	1.6	1.5	1.7	1.7	1.4	2.1	0.84	<0.7	0.91

Cadmium	0.054	0.1	0.079	0.11	0.11	0.071	0.12	0.043	0.052	0.028
Chromium	7.5	14	8.2	12	12	9	12	4.2	4	5
Cobalt	1.7	3	2.3	3.2	3.2	2.3	3.4	1.3	1.1	1.3
Copper	2.1	4.3	3	3.8	3.8	2.7	4.6	0.95	1.6	1.1
Lead	2.6	4.5	2.8	3.5	3.5	3	4.2	2.2	2.2	2.1
Mercury	<0.02	0.035	0.025	0.028	0.028	0.022	0.04	<0.02	0.026	<0.02
Molybdenum	0.41	0.62	0.54	0.74	0.74	0.48	0.61	0.23	0.32	0.33
Nickel	5	9.4	6.2	8.1	8.1	6	7.6	3.4	2.9	3.7
Selenium	0.19	0.45	0.21	0.3	0.3	0.18	0.37	<0.08	<0.08	<0.08
Zinc	11	18	13	16	16	13	18	34	11	17
CEC	19.6	37.2	44.8	45.9	45.9	32.9	47.4	3.87	13.1	3.58
EC	0.107	0.106	0.129	0.144	0.144	0.129	0.188	0.044	0.07	0.053
OM	13.6	27.9	23.9	26.4	26.4	15.3	29.4	1.98	5.88	2.23
Gravel	0.2	0.6	1.5	0.3	0.3	0.2	0.6	0	0	0
Sand	71.2	34.9	56.7	46.1	46.1	63.6	34.8	92.6	84.9	93.3
Silt	17.6	36.6	21.2	27.4	27.4	23	32.6	5.7	6.3	4.2
Clay	11.1	28.5	22.1	26.5	26.5	13.4	32.6	1.6	8.7	2.5
P	9.9	8.8	7.2	7.9	7.9	7.5	6.2	12	19	21
pH	4.9	4.6	4.6	4.9	4.9	5	4.9	5.7	5.2	5.2
Moisture	30.12	44.77	52.84	65.93	65.93	35.01	54.06	8.59	13.45	10.76

N	0.3	0.46	0.44	0.39	0.39	0.28	0.47	0.03	0.21	0.05
K	81	58	68	69	69	81	63	34	41	38

Table 3: Raw data for TEs, hydrocarbons and fruit quality variables in pin cherry fruits

Site ID	A1	A10	A2	A2	A3	A4	A5	A6	A7	A8	A9	N3 bare hands	N3 bare hands + deet	N3 gloves	N3 gloves	N4 gloves	S1	S10	S3	S3	S4	S5	S6	S7	S8	S9
Site	SS1	SS1	SS1	SS1	SS1	SS1	SS1	SS1	SS1	SS1	SS1	RS1	RS1	RS1	RS1	RS1	SS2	SS2	SS2	SS2	SS2	SS2	SS2	SS2	SS2	SS2
Site Name	Aurora	Aurora	Aurora	Aurora	Aurora	Aurora	Aurora	Aurora	Aurora	Aurora	Aurora	Fort Chipewyan	Fort Chipewyan	Fort Chipewyan	Fort Chipewyan	Fort Chipewyan	Sandhill	Sandhill	Sandhill	Sandhill	Sandhill	Sandhill	Sandhill	Sandhill	Sandhill	Sandhill
Site Type	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Natural	Natural	Natural	Natural	Natural	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed	Reclaimed
C1 Chrysene	0.459011193	0.678607633	0.213584545	0.354427388	0.356260883	1.141360611	0.926481733	0.739555455	0.926481733	0.111837866	1.292459855	0.19062605	0.0775218 6	0.15638073	0.19699 85	0.11715163	0.208 31 863	0.163 19 117	0.360 89 03	-0.0 23 14 32	-0.0 24 47 82	0.198 48 582	0.140 68 083	0.0 248 834 42	0.278 92 412	0.102 45 372

C1 Dibenzothiophene	0.202740874	1.225501477	0.391545633	0.021277796	0.863120044	0.471743848	0.752998441	0.109964645	0.521010444	1.508945888	2.392207111	0.01472672	0.1432797 1	0.04089859	NM	-0.01053 99	0.125931 02	-0.022 9507	0.443 6567 9	0.081 0383 3	0.107 6312 4	0.297 5847	0.220 1706 1	0.0 8437 889	0.217 113	0.1 9365 13 8
C1 Fluorene	-0.1380580 83	2.397 0676 8	0.006 8492 6	0.115 6057 7	0.267 5492 5	0.158 6552 8	-0.033 2083	0.004 1020 85	0.005 0793 05	1.667 9057 7	1.727 7161 2	-0.29444 04	0.057 6046 8	-0.20 56681	NM	-0.33 761 67	-0.330 6985	-0.344 4138	1.052 0652 9	-0.330 6985	-0.330 6985	0.449 1369 2	0.021 2664 2	-0.3 3069 847 1	0.020 4054 5	0.0 6173 21 6
C2 Chrysene	1.430709938	2.680 3814 6	1.126 0578 6	1.055 0496 6	0.990 0991 6	5.021 8117 3	2.715 0878 5	1.133 5904 4	2.715 0878 5	0.095 1304 3	3.226 8542 6	0.45583 645	0.362 9932 8	0.74473 708	0.53 889 859	0.42 275 29	0.687 9636 3	0.481 2310 2	1.087 7472 5	0.417 6787 1	-0.343 7392	0.304 3162 6	0.348 7277 3	0.4 4980 854 4	1.561 5034 1	-0.0 5386 85
C2 Dibenzothiophene	1.165647301	7.267 9464 8	2.598 3144 5	0.407 9763	7.366 6249	3.228 0252 5	4.994 8484 4	0.967 4187 3	4.100 0977 22	9.378 0911 9	13.64 7670 7	0.33 596 795	0.783 2792	0.41 973 547	NM	0.06 865 994	0.521 4984 7	0.319 7827 4	2.086 7838 4	0.622 8080 1	0.610 4565 9	1.526 4903	1.168 0799 3	0.5 3506 071 6	1.148 9990 65	0.9 4455 98 8
C2 Fluorene	0.245066877	5.050 0789 2	0.282 6668 63	0.356 9609 2	0.759 8091 7	0.345 5746 7	0.761 4496 4	0.373 3469 4	0.625 8682 6	3.993 0101 8	4.886 5293 8	-0.19 531 1	0.173 2790 4	-0.18 018 48	NM	-0.05 145 25	-0.054 0747	-0.049 8582	1.203 9455 2	0.123 3714 3	0.077 4819 2	0.609 6796	0.210 1093 8	0.0 7752 559	0.131 7101 2	0.1 6863 95 3
C2 Naphthalene	-0.1163614 52	-0.900 0367 2	8.934 8094 2	-1.245 3562	-1.798 1038	0.820 4207 8	1.689 3364 6	-1.559 5917	1.689 3364 6	2.012 5464 2	1.547 0542 6	-0.77 239 64	4.831 2686 5	-0.32 661 32	-0.57 217 8	0.05 864 044	0.539 1004 6	0.327 7261 1	1.814 5473 6	0.037 8273 5	-1.903 9315	2.172 7934 5	-0.187 7129	-1.3 3470 080 2	0.311 7858	-1.0 5737 75

C2 Phenanthrene	2.929797918	6.16576692	0.4260861	3.26489937	3.0902416 5	13.121596 1	5.669623 19	2.735551 92	5.669623 19	0.033963 68	8.205651 62	0.53491006	0.0488583 8	0.69998509	0.52829863	0.17480512	0.7171585 9	0.6173267 8	0.9040514 4	0.9806070 6	0.4893090 6	0.9836755 9	1.5653297	0.8822120 27	1.6487740 6	0.8017895 8
C3 Chrysene	0.0283514 74	0.1150309	-0.0262257 7	0.1275577	0.1780120 7	0.7353332	0.1393096 3	0.2147196 2	0.1393096 3	-0.006511 7	0.1583489 9	-0.0104502	-0.0235531	-0.0111362	-0.0350661	-0.0263917	0.0084716 8	-0.017723	0.0484844	0.1719123	0.0560756 1	-0.0249165	0.0036012 27	0.0476261 78	0.1671582 1	-0.0293838
C3 Dibenzothiophene	0.8378734 8	8.3064430 7	2.6684842 7	0.5323933 3	5.7997821 6	3.6338180 5	4.7653872 1	1.1683950 7	4.0006871 6	11.59172 63	15.31949 497	0.29188798	0.6948022 4	0.3624461	NM	0.01514292	0.4632491 8	0.4963873 2	2.2098428	0.6949164 1	0.7604700 7	1.2570297 5	1.5668481	0.7597435 57	1.4478648 1	0.9637210 5
C3 Fluorene	-0.3043622 74	6.6712091 6	0.1291224	0.1747061 5	0.7914458	0.2227094 8	0.3279483	-0.030436 23	0.9855795 1	5.9926651 5	6.4408621 8	-0.4931127	0.2842062 2	-0.4283327	NM	-0.2665074	-0.4159595 9	-0.3849029	2.0121847 3	-0.4159595 9	-0.4159595 9	0.6816908	-0.4159595 9	-0.4159590 49	0.0627962 8	0.0237437 43
C3 Naphthalene	0.2717502 05	0.4275139 7	-0.1394287	-0.4811495	-0.6871607	0.4549348 9	1.1149481 1	-0.807999 6	1.1149481 1	0.3394852 2	1.4621268 7	0.13987316	0.0961215 4	0.12964745	0.10814718	-0.1377363	0.0043929 64	0.1415686 1	-0.0300374	-0.3223053	-0.7040693	0.7165996	-0.4514357	-0.5067361 52	0.0237548 8	-0.4860445
C3 Phenanthrene	2.8755906 64	6.9679532	0.4724875 6	2.9095007 6	2.2879764 5	10.284749 3	7.0339328 1	2.2842898 7	7.0339328 1	-0.211397 3	9.7777254 2	0.98564422	0.9513817 1	3.74367442	1.19008119	0.92412135	1.7061158 7	1.7552364 5	1.0806923	0.8991914 9	0.2262066 3	2.5793835 7	1.4373021 2	1.7307924 67	2.1583313 5	0.4945292 9

C4 Chrysene	-0.0088931 58	0	0	0	0	0	0.0874985	0	0.0874985	0	0	-0.0120 12	-0.0180653	-0.0144271	-0.0276325	-0.0177604	0.0059744 9	-0.0097962	0	0	0	-0.0310167	0	0	0	0
C4 Dibenzothiophene	2.1912362 3	24.2875902	3.1382081 2	0.4282938 8	8.7028475	5.7699232	14.9244243	1.5984686 6	7.6723380 3	36.4506 5	48.3430112	1.40765058	1.8775326	1.10588119	NM	-0.0399265	1.3003132 2	2.5644266 1	8.1639237 8	0.8920333 3	1.2669622 9	4.0232352 5	3.2930930 1	0.4319774 17	3.1091398	1.3028609 4
C4 Fluorene	-0.4315095 22	3.7579568 6	-0.4315095	-0.4315095	0.0181499 5	-0.4315095	0.0458759 9	-0.4315095	0.4615055 9	4.0270219 4	3.8613656 1	ND	ND	ND	ND	ND	-0.4854313	-0.3830149	0.9559098	-0.4854313	-0.4854313	0.4019063 8	-0.4854313	-0.4854313 05	0.0082852 4	-0.4854313
C4 Naphthalene (Butyl)	0.1700089 35	0.9406618 9	-0.0000586 8	-0.0074833 6	-0.0081731 2	0.0190204 9	0.3297448 5	-0.0087626 6	0.3297448 5	0.0190641 2	0.8441472 3	-0.0092342	-0.0287564	0.05175506	0.05174547	-0.0462171	-0.0024945 1	-0.0031318	0.0667260 9	-0.0048123 3	-0.0051712 8	0.0048410 71	-0.0094000 92	-0.1068305 32	-0.0055729 2	-0.0089259 9
C4 Phenanthrene	0.4913111 73	2.3809055 4	0.3546527	0.5425900 2	0.3142692 7	1.6829464 9	1.9612118 9	0.4768643 7	1.9612118 9	0.0914816 8	2.6855425	-0.0103372	-0.0154973	0.16147418	0.08643433	-0.0796939	0.1838745 5	0.3405836 3	0.6324691 1	0.2747456 9	0.0151598	0.3064430 4	0.3223638 5	0.1270357 3	0.4683258	0.1826696 2
Dibenzothiophene	-0.0481610 56	0.3342645 1	0.0352088 6	-0.0048161 11	0.0394214	0.0539008 4	0.0013954 9	-0.0048161 11	0.0060330 1	0.2831515 6	0.2813621 2	-0.0422661	0.0279157	-0.0306209	NM	-0.0326699	-0.0029449 5	-0.0046272 4	0.2204730 5	0.0093168 5	0.0025791 83	0.0065976 09	0.0043096 08	0.0094578 14	0.0043365 23	0.0034025 45

Retene	0.079884056	0.34412525	0.17225727	0.00555937	-0.0442087	0.19149652	0.35059906	-0.0241674	0.35059906	0.21129436	0.76898679	0.01156137	0.0597112 2	0.05599839	0.05479781	-0.0189535	0.04696823	0.16039014	0.12516561	0.02453348	-0.0449195	0.12727634	0.00592235	-0.0162554 44	0.02934272	-0.0318214
Acenapthene	-0.0412236 12	0.01492782	-0.4546134	-0.5205898	-0.6227835	-0.5443744	-0.0073433	-0.3663255	0.33190228	-0.0046513 4	-0.0423844	-0.2213752	0.1145122 3	-0.1358924	NM	-0.1953885	0.08779598	0.32704865	-0.6628 59	-0.5493 911	-0.5909842	0.36381299	-0.5417 23	-0.6510008 35	-0.618366	-0.4493369
Acenapthylene	-0.0384567 51	-0.0025 2274	-0.0079 1643	-0.0096 8594	-0.1178 81	-0.1047 4784	-0.0037 0023	-0.1326 6644	-0.0013 4123	-0.0036 7398	-0.0012 9583	-0.0479 0907	-0.020 5159	-0.0469 4631	NM	-0.0120 2036	0.00150928 1	0.01499869	-0.1346 5682	-0.1064 8007	-0.1270 1 44	0.00339395	-0.1259 586	-0.1297 432 22	-0.119 4516	-0.1003 6372
Anthracene	0.0078 5096	-0.0116 73	-0.0074 421	-0.0080 2973	-0.0079 6014	-0.0075 6102	-0.0004 1466	-0.0078 024	0.0273 0438	-0.0015 2502	-0.0011 8507	-0.0324 4497	0.0284 6979	-0.0046 6614	NM	-0.0116 3403	0.00434037 6	0.00227811	-0.0078 9997	-0.0082 1971	-0.0077 5634	0.00246 1619	-0.0079 3866	-0.0073 9671 32	-0.007 2669	-0.0079 6346
Benz[a]anthracene	0.0277 0538	0.03844769	-0.0811 1112	-0.1116 6629	-0.1074 7468	-0.1089 8951	0.0185 6166	-0.1195 938	-0.0000 7207	0.0299 7402	0.0323 9385	-0.0063 0627	0.0609 8684	0.01038 708	NM	0.01066 965	0.00590 1593	0.00904 002	-0.0094 6777	-0.1162 1881	-0.1276 9117	0.00032 9934	-0.1201 5581	-0.1110 5886	-0.0092 9165	-0.1230 8006
Benzo[a]pyrene	-0.0060 08773	-0.0021 7832	-0.0028 8008	-0.0040 8436	-0.0040 612	-0.0039 689	-0.0006 7678	-0.0074 4737	-0.0020 1694	-0.0028 0835	0.0039 0506	-0.0237 8001	0.0095 5428 4	-0.0097 2008	NM	-0.0096 6656	0.00019 3523	0.00548 9495	-0.1014 9717	-0.0053 7193	-0.0073 4393	-0.0013 3081	-0.0074 66	-0.0088 3865 62	-0.0068 1581	-0.0087 213

Benzo[b]fluoranthene	0.0187330 99	0.0160392 6	-0.0813808	-0.0761132	-0.0756063	-0.0816 7827	0.0519179 6	-0.1021836	-0.0038356	0.0058878 5	0.0330374 3	-0.0232407	0.0709708 2	0.00973383	NM	-0.0222444	0.0295537 9	0.0295537 9	-0.1206039	-0.0820 1866	-0.1127349	-0.0461227	-0.1147477	-0.1028283 26	-0.1123344	-0.1275685
Benzo[g,h,i]perylene	0.0142801 78	-0.0113478	-0.0829857	-0.0836 659	-0.0934576	-0.0881613	-0.0029066	-0.0973823	-0.0136391	-0.0204899	0.0020920 1	-0.0297608	0.0286141 8	-0.0161058	NM	-0.0127587	-0.0094469	-0.0178655	-0.1202637	-0.0705921	-0.1030212	-0.0178488	-0.1078733	-0.1032442 35	-0.1104782	-0.1183346
Benzo[k]fluoranthene	0.0081781 37	0.0114377 2	-0.0812098	-0.0848958	-0.0926666	-0.1093117	0.0030244 1	-0.1132546	-0.0114875	-0.0031441	0.0141645	-0.0268755	0.0557385 9	0.00290968	NM	-0.0183826	-0.0120969	-0.0339752	-0.1231807	-0.0095775	-0.1123041	-0.0040789	-0.1054 3797	-0.1084674 15	-0.1094932	-0.1150511
Dibenzo[a,h]anthracene	-0.0063181 34	-0.0078209 2	-0.1374161	-0.1503843	-0.1720252	-0.1646581	-0.0005257 2	-0.1608859	-0.0035069 4	-0.0085 81	-0.0072983 1	-0.0301841	-0.0294623	-0.0424515	NM	-0.0400985	-0.0039194 5	-0.0021863 8	-0.1855876	-0.1748014	-0.1720717	-0.0023038	-0.1757725	-0.1772254 86	-0.1755137	-0.1787592
Fluoranthene	0.0437315 38	0.0591396 7	-0.3881986	-0.4061 47	-0.3984899	-0.3908835	-0.0002626	-0.3927391	0.0391689 5	0.0163563	0.0614623	-0.0482099	0.1442778 2	-0.0197746	NM	-0.0231494	0.0015 4253	-0.0047677	-0.4024061	-0.4076717	-0.4147077	-0.0083 2473	-0.3948205	-0.4035751 84	-0.4023698	-0.4010393
Indeno[1,2,3-c,d]pyrene	-0.0092848 56	-0.0312 74	-0.1202844	-0.1170515	-0.1254044	-0.1351161	-0.0015664 5	-0.1436455	-0.0036569 1	-0.0026 7946	-0.0012 2274	-0.0056 4018	0.0038 9609	-0.0400 0049	NM	-0.0503333	-0.0041 7992	-0.0035 5456	-0.1452206	-0.1190474	-0.1367639	-0.0037 6781	-0.1498899	-0.1376 06322	-0.1348896	-0.1536599

Pyrene	0.118977771	0.249807334	-0.37440663	-0.36568221	-0.35879792	-0.42006674	0.132093532	-0.40158567	0.132131384	0.197729044	0.225808133	0.00695 13	0.1444820 8	0.02789 501	NM	0.02701 836	0.0 89 21 44 2	-0.0 22 60 88	-0.3 80 79 68	-0.4 58 16 44	-0.4 58 80 18	-0.0 26 71 91	-0.4 24 39 97	-0.4 098 452 48	-0.4 19 15 38	-0.4 38 29 5
Arsenic	0.0 015	< MDL	0.0 01	0.0 01	0.0 01 7	0.0 01 2	0.0 01 6	< MDL	0.0 02 3	0.0 01 6	< MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0 01 2	0.0 01 7	< MDL	0.0 01 1	0.0 01 5	0.0 01 9	0.0 01 7	<MDL	< MDL	< MDL
Boron	8.5	11	9.8	9.8	7.3	10	9.8	12	20	16	13	4.5	4.2	4.3	4.3	4.3	13	9.1	9.6	14	8	17	11	10	15	24
Cadmium	<MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	<MDL	<MDL	<MDL	<MDL	<MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	<MDL	< MDL	< MDL
Chromium	0.0 14	0.0 16	0.0 15	0.0 15	0.0 2	0.0 14	0.0 18	0.0 15	0.0 23	0.0 19	0.0 16	0.01 4	0.014	0.01 2	0.01 2	0.01 2	0.0 22	< MDL	< MDL	0.0 17	< MDL	0.0 16	< MDL	0.0 18	0.0 14	< MDL
Cobalt	0.0 083	0.0 05 2	0.0 04	0.0 04	0.0 05 6	0.0 06 3	0.0 05 3	0.0 04	0.0 07 6	0.0 06	0.0 04 1	0.00 27	0.002 2	0.00 26	0.00 26	0.00 44	0.0 03 5	0.0 04 8	0.0 03 8	0.0 03 2	0.0 05 5	0.0 09 9	0.0 04 8	0.0 033	0.0 03 6	0.0 04
Copper	2	1.5	1.5	1.5	0.9 4	1.4	1.1	0.9 2	1.4	0.9 8	1.7	1.5	1.4	1.5	1.5	0.95	1.4	1.4	3.2	2.6	2.2	1.6	1.5	1.2	2.2	1.7
Iron	6.5	5.5	5.6	5.6	7.7	6.2	5.1	4.9	6.9	5.9	4.8	8.2	6.7	8.4	8.4	4.4	7.9	8.5	7.5	7.9	9.5	5.9	8	4.6	7.1	5.7
Lead	<MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	<MDL	<MDL	<MDL	<MDL	<MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	<MDL	< MDL	< MDL

Magnesium	390	360	350	350	360	320	330	320	450	320	330	220	200	250	250	260	290	320	340	360	350	320	340	300	320	520
Mercury	<MDL	<MDL	<MDL	<MDL	0.000013	<MDL	<MDL	0.000018	<MDL	<MDL	<MDL	0.000039	0.000046	0.000047	0.000047	<MDL	0.000014	0.000018	0.000019	0.0001	0.000018	<MDL	0.000018	0.0001 1	0.000012	<MDL
Molybdenum	0.011	0.013	0.01	0.01	0.014	0.0056	0.014	0.028	0.025	0.0095	0.0068	0.045	0.046	0.043	0.043	0.03	0.018	0.014	0.027	0.015	0.029	0.012	0.0098	0.047	0.034	0.0046
Nickel	0.07	0.085	0.092	0.092	0.11	0.1	0.094	0.051	0.076	0.067	0.07	0.063	0.064	0.062	0.062	0.08	0.055	0.073	0.049	0.046	0.063	0.12	0.077	0.054	0.048	0.065
Selenium	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0097	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Zinc	3.5	3.7	3.2	3.2	3.2	3.7	2.5	2	3.2	2.5	3.4	2.6	1.9	2.7	2.7	2.1	2.5	2.7	2.9	2.9	2.7	3.1	3.1	3.1	3	3.8
TAnC	24.20	17.50	19.60	19.60	12.82	19.08	18.30	14.32	10.06	19.83	19.58	8.77	8.77	9.76	6.23	19.32	16.47	9.81	10.91	18.55	21.93	18.94	15.87	17.93	12.64	11.91
TAA	48.90	63.62	63.38	63.38	34.17	61.90	46.83	58.41	29.30	62.01	45.64	42.22	42.22	35.73	41.46	68.21	50.07	42.88	56.79	64.30	56.65	44.26	57.83	56.79	60.55	56.19
TAC	16.55	9.16	9.31	9.31	8.58	9.50	6.70	7.75	13.95	10.39	8.44	5.10	5.10	5.39	7.24	8.65	9.03	10.22	8.14	12.72	7.85	8.26	12.98	9.37	8.83	6.72
TPC	22.38	26.95	26.20	26.20	13.09	20.71	19.65	22.07	17.86	18.81	20.47	14.67	14.67	16.40	20.96	25.57	28.87	18.35	17.43	25.20	20.64	20.93	32.28	26.03	18.29	22.15
VitaminC	116.76	273.38	150.93	150.93	155.31	120.14	177.96	115.62	102.34	136.28	204.34	196.16	196.16	129.42	209.55	174.21	156.37	144.90	72.75	122.30	129.16	105.22	121.16	146.08	196.49	189.89

Fruitp H	3.78	3.58	3.61	3.61	3.81	3.67	3.83	3.79	4.17	3.84	3.77	3.37	3.37	3.42	3.41	3.46	3.66	3.86	3.71	3.77	3.56	3.63	3.88	3.56	3.74	3.79
Water Conte nt	0.61	0.73	0.73	0.73	0.73	0.73	0.66	0.73	0.86	0.73	0.78	0.64	0.58	0.58	0.58	0.69	0.76	0.76	0.80	0.76	0.76	0.76	0.78	0.76	0.70	0.75

ND = Not Detected; NM = Not Measured

Table 4: Raw data for TEs, hydrocarbons, and soil properties in pin cherry soil

Sampl e ID	A1	A1 0	A2	A3	A4	A5	A6	A7	A8	A8	A9	N3 repli cate 2	N3	N4	S1	S10	S2	S3	S4	S5	S6	S7	S8	S9
Site	SS 1	SS 1	SS 1	SS1	SS1	SS1	SS1	SS1	SS1	SS1	SS 1	RS1	RS1	RS1	SS 2	SS2	SS 2	SS 2	SS2	SS2	SS2	SS 2	SS 2	SS 2
Site Name	Au rora	Au rora	Au rora	Aur ora	Aur ora	Aur ora	Aur ora	Aur ora	Aur ora	Aur ora	Aur ora	Fort Chi pew yan	Fort Chi pew yan	Fort Chi pew yan	San dhil l	San dhil l	San dhil l	San dhil l	San dhil l	San dhil l	San dhil l	San dhil l	Sa nd hill	San dhil l
Site Type	Re cla im ed	Re cla im ed	Re cla im ed	Rec lai me d	Rec lai me d	Rec lai me d	Rec lai me d	Rec lai me d	Rec lai me d	Rec lai me d	Rec lai me d	Nat ural	Nat ural	Nat ural	Rec lai me d	Rec lai me d	Rec lai me d	Rec lai me d	Rec lai me d	Rec lai me d	Rec lai me d	Rec lai me d	Re cla im ed	Rec lai me d
C1 Diben zothio phene	4.36	1.515	3.786	1.985	1.898	-0.3661799 69	0.422	3.228	10.66	6.375	3.968	1.005	1.005	0.056	9.597	3.789	10.137	8.602	5.465	8.361	5.333	14.489	11.209	11.275

C1 Fluorene	0.639	-0.916712	0.758	-1.23807263	-0.8245534	-2.1424948	-1.1934360	0.788	2.126	1.874	0.581	2.454	2.454	-0.601743718	0.783	-0.703863498	2.257	1.136	-0.127826834	-0.777593574	-1.3105985	1.716	2.023	0.231
C2 Dibenzothiophene	7.166	4.174	8.221	4.192	6.568	-1.0425838	1.594	8.338	22.398	14.347	10.427	3.427	3.427	5.875	23.473	9.437	10.768	22.249	14.469	12.09	5.503	21.057	17.617	15.395
C2 Fluorene	11.191	3.747	5.82	5.075	6.28	0.131	3.274	5.729	16.525	11.501	9.165	6.161	6.161	2.39	7.589	2.979	6.136	10.696	6.407	6.397	5.916	9.259	7.134	9.262
C3 Dibenzothiophene	4.711	3.318	6.286	3.973	3.078	-0.5176914	1.925	6.113	16.976	11.278	7.98	1.339	1.339	5.127	17.23	6.205	6.364	19.186	4.123	4.654	4.977	12.84	11.098	8.67
C3 Fluorene	10.966	10.629	10.186	16.253	14.717	-5.4438812	5.445	22.199	38.518	30.122	14.053	10.523	10.523	3.859	22.669	11.238	17.862	13.954	21.776	19.111	10.139	17.427	14.796	13.862
C4 Dibenzothiophene	69.581	39.14	39.478	42.308	42.93	-2.5267539	5.957	50.307	142.804	105.615	63.736	29.376	29.376	21.92	90.682	23.395	55.438	148.621	26.133	23.976	100.23	67.847	61.992	45.033

C4 Fluorene	6.847	5.965	5.262	7.679	6.075	-0.956716115	4.491	10.857	23.781	17.74	8.094	6.654	6.654	3.096	13.755	6.897	8.477	9.331	8.131	6.746	5.886	8.332	9.526	6.848
Dibenzothiophene	0.454	0.287	0.34	0.439	0.415	-0.178047629	-0.041569014	0.754	2.437	1.43	0.805	0.44	0.44	0.075	3.255	1.297	4.471	1.609	1.173	1.762	1.432	4.675	5.359	3.139
C1 Chrysene	45.9442523	17.15267822	32.43513099	25.28742605	21.76859668	16.73954934	8.981821974	23.20533374	38.9761834	31.45009634	35.32397574	8.100500694	8.100500694	4.43099079	54.82072787	48.02303184	66.91119696	55.7272994	49.87524079	45.89537206	75.43937598	84.28060503	88.60544489	74.82381661
C2 Chrysene	170.3788677	79.795381677	123.7807773	91.34749283	80.39500124	59.41823013	46.12484064	101.9081636	170.2588809	109.8036814	120.4884262	16.02148455	16.02148455	12.50194893	238.6449589	131.471124	214.2294793	168.5874827	136.5925237	172.8521811	275.6137069	236.3480624	254.0839224	246.3249003
C2 Naphthalene	9.607115166	4.099498001	8.049087099	4.520542948	5.791623475	0.427718232	-0.650856973	6.059376753	5.391063046	1.781516376	2.620320325	10.1776073	10.1776073	13.27381325	6.274659366	6.631250735	14.55558755	5.524036027	11.04374471	3.442797863	8.911204026	17.65046253	24.41368857	13.65605702
C2 Phenanthrene	18.9738061	8.7709217 3	12.673089 2	12.60967308	13.93094169	5.41413857	3.009974176	9.476978524	16.06059804	11.72957026	15.40993018	5.13815118	5.13815118	4.517422095	12.11426 25	13.52146124	23.56893916	18.59788174	12.07810203	10.98818554	13.93203362	25.76622244	30.60098 21	25.34718128

C3 Chrysene	15.07 3581	4.37 6180 02	7.97 0704 1	7.7 8067 3964	4.1 2809 3998	2.7 4975 3664	3.2 4647 7681	3.9 9062 1679	7.5 2961 0837	6.1 5977 3367	7.8 6527 7371	2.45 6130 831	2.45 6130 831	5.65 4404 562	7.9 5905 0332	6.6 9301 3961	8.6 5639 8507	9.3 8708 8869	6.4 5023 0679	5.6 4460 228	20. 1809 9409	11. 2233 6894	12. 6612 358	12. 3211 2886
C3 Naphthalene	14. 8347 488	5.2 1766 075	10. 1512 43	6.6 4299 2796	6.8 5022 2901	3.0 4278 3343	1.2 6554 5544	6.7 9862 3876	7.3 1512 0714	5.7 4852 0198	8.3 9055 2198	6.30 3074 418	6.30 3074 418	5.18 7837 058	7.8 5832 957	6.9 7784 0492	13. 0588 8408	7.6 3525 633	14. 9230 9146	7.2 1556 0275	6.9 6149 0407	16. 6226 6989	22. 0954 098	13. 9064 3058
C3 Phenanthrene	26. 1780 129	13. 5315 12	19. 5844 876	19. 9377 6531	33. 2729 6614	11. 1388 4759	8.3 2110 5007	18. 8534 3916	27. 7668 5734	15. 6794 0798	20. 4697 0815	20.8 6984 698	20.8 6984 698	8.41 7285 766	14. 4188 2436	17. 3550 0701	23. 8481 2283	44. 2905 4402	14. 8812 4111	12. 4277 4141	25. 9352 3808	26. 8244 4525	31. 9126 11	26. 1069 3998
C4 Chrysene	13. 5314 577	4.3 6229 651	8.2 3938 991	8.5 2330 2476	3.9 4863 8047	2.1 9099 4168	3.6 6941 3521	1.2 2054 4249	6.5 9049 8785	5.8 3676 6208	6.4 8358 1525	2.54 2526 895	2.54 2526 895	5.10 4723 511	5.3 5252 8467	6.0 7784 7934	6.5 2372 173	8.1 7613 4527	4.8 8635 6901	4.8 2523 3419	19. 0572 426	6.1 9993 2718	8.1 9339 071	8.3 8943 5313
C4 Naphthalene (Butyl)	9.7 8253 508	4.2 1108 759	6.8 1054 935	4.7 1223 6092	7.5 5269 5966	3.6 4934 0183	3.5 3640 8034	5.0 4726 4822	6.1 6780 3572	4.3 5674 573	6.5 8065 0473	4.07 1874 247	4.07 1874 247	3.99 1011 778	3.9 6490 4375	4.0 9578 2083	9.3 5124 1958	4.2 1115 8387	7.1 1039 2603	3.0 4990 5955	5.3 1173 4981	9.4 1658 1254	14. 2034 754	7.9 9372 3505
C4 Phenanthrene	25. 3477 153	14. 9957 305	20. 3569 237	21. 2276 8694	32. 1112 9781	14. 8083 831	7.4 5277 4951	18. 2685 4352	19. 9495 8359	14. 7463 6421	29. 3770 8779	21.7 4269 914	21.7 4269 914	15.1 0534 037	12. 8554 6043	17. 7219 8323	18. 3035 7288	31. 4138 2424	8.4 0883 8617	12. 2144 4088	35. 5830 6967	23. 4034 783	21. 5892 625	23. 2756 6299

Retene	9.643868853	8.447945022	17.391222	7.176366884	51.15016272	7.9066423 5	1.906160108	8.929814603	2.705385426	2.985034062	5.524855072	35.63158717	35.63158717	7.21905677 7	3.058736608	14.225365	4.235647434	105.57183 61	-1.060539128	5.179955618	13.90900857	17.30633642	7.156324 54	9.431650011
Acenapthene	0.783555596	0.103123066	0.156477 68	0.154141232	-0.434304093	-0.3118881 59	-0.3588682 25	-0.2049976 88	-0.0672367 01	-0.0992120 03	0.250295121	0.91178121 7	0.91178121 7	0.88455094 5	0.538394105	-0.3057278 14	0.360962937	0.108820018	0.398819663	-0.4447045 73	0.033379571	0.12697192 7	-0.2 47093 3	0.033722 46
Acenapthylene	0.266537 18	0.257918 28	0.136116 39	0.162637369	0.068909773	0.0952535 61	-0.0070793 89	0.038935 25	0.786872216	0.509454939	0.260446689	2.01240158 7	2.01240158 7	1.18203748 2	0.366705509	0.003809 7 3	0.268748378	0.047332467	0.188913004	-0.0243091 91	0.088261127	0.09175921 2	0.3 296576 3	0.005062211
Anthracene	0.344249 72	0.244048 1	0.236997 78	0.492372609	0.519674 51	0.2663165 48	0.0514874 02	0.296864128	0.737678941	0.535183831	0.533179616	0.26313726 5	0.26313726 5	-0.00202 6049	1.592050489	0.798114486	1.547234006	1.049445822	0.964750777	0.6679260 95	0.833819679	1.53178367 4	1.837137 08	1.310154948
Benz[a]anthracene	0.267109 38	0.358764 36	0.456670 55	0.610648441	0.548929664	0.5256729 13	0.2914273 76	0.476394716	2.141797333	0.711297178	0.679431605	1.21826366 6	1.21826366 6	-0.08167 2951	4.874154449	2.6017143 13	5.093319739	3.186908 21	2.162081282	2.6828392 59	3.174799157	4.75249849 8	5.586999 718	4.406607614
Benzo[a]pyrene	0.676193 79	0.577335 79	0.423428 36	0.919925286	0.919286366	0.9973776 72	0.1742653 54	0.241154329	3.347705542	1.083213589	0.887240368	1.76013200 1	1.76013200 1	0.32062 5464	5.491258982	2.6904785 87	5.163636665	3.990959473	2.617667626	2.4391844 36	5.051060519	5.67923078	7.809 94 124	4.399439328

Benzo[b]fluoranthene	1.184624432	1.455392555	0.853425532	2.417580173	1.291434111	1.223010671	0.572712251	1.421024009	5.420804488	3.056799105	2.312038211	1.18586748 4	1.18586748 4	0.29306466 5	2.922467015	1.483416879	3.056470394	2.467184114	3.513473588	1.572919984	3.378779684	2.799185803	3.632128223	2.825199222
Benzo[g,h,i]perylene	2.583275088	2.751775581	1.576781	4.257276104	0.897990368	1.525644 7	1.617325902	0.933336089	5.869715864	4.892830125	3.658129418	0.65651702 4	0.65651702 4	0.19055659 8	5.860235052	2.852003945	5.094833017	4.075758748	3.097178408	3.716669153	5.161874557	4.766904049	6.661651046	4.962878
Benzo[k]fluoranthene	0.334490155	0.402415666	0.349612622	0.879975129	0.737687442	0.528875462	0.337299155	0.369677025	2.284669141	1.343827852	0.620709901	1.04104032 1	1.04104032 1	0.09733850 1	1.894500117	0.824019362	1.935070973	1.313279719	2.593688868	0.764863266	1.697797676	1.715909586	2.134358881	1.652870628
Dibenzo[a,h]anthracene	0.503123394	0.147465188	0.199999198	0.967421846	0.280875438	0.224575782	0.157831873	0.095359915	1.178403257	0.807838171	0.452485618	0.11957955 1	0.11957955 1	0.00172201 7	1.885492744	0.939770173	1.766559409	1.438626848	0.734826803	0.969545 51	1.933894547	1.909758771	2.066118 73	1.724373029
Fluoranthene	0.314373738	0.406272887	0.516959 51	0.407756043	1.312248255	0.539914 12	-0.077737331	0.119945988	2.169618632	0.757725704	0.765511 3	2.33970209 3	2.33970209 3	0.75015854	1.720147604	0.661297865	1.634546793	0.986085595	1.085549213	0.640270241	0.794252914	1.056974896	1.953060602	1.158660759
Indeno[1,2,3-c,d]pyrene	1.076551 73	0.967 6582 5	0.515997 833	2.417506 03	0.479567 618	0.893398 4 12	0.914087 3 05	0.567163 544	2.701894 22	2.590682 57	1.934429 994	0.73587 0786	0.73587 0786	0.13214 9297	1.972454 842	0.988894 548	2.020027 154	1.313105 377	2.414688 688	1.233892 79	2.128971 058	1.529971 03	2.530278 96	2.078239 349

Pyrene	0.779851 2	1.226978 32	0.365225 68	0.932765 061	0.524565 61	0.478779 389	0.176541 282	0.370599 547	3.816506 362	1.828243 981	1.750445 931	3.749930 441	3.749930 441	1.172378 303	5.141935 846	2.540250 555	5.749879 672	3.275835 342	2.784406 371	2.697710 408	3.856414 145	4.424866 571	6.145207 83	4.216333 444
Arsenic	1.6	1.7	1.4	1.4	1.3	1.5	1.7	1.4	2	2	1.9	1.2	1.2	0.91	2.6	1.2	1.1	1.3	1	2.3	1.2	0.89	1.7	1.9
Cadmium	0.03	0.03	0.04	0.03	0.03	0.02	0.02	0.03	0.02	0.02	0.05	0.03	0.03	0.03	0.07	0.05	0.03	0.04	0.04	0.09	0.03	0.03	0.04	0.03
Chromium	5.2	5	7.8	4.9	5.3	5	5.1	5.6	5.5	5.5	5.8	5.4	5.4	5	13	6.6	3	6.2	4.2	15	6.7	2.9	8.4	4.5
Cobalt	1.3	1.7	1.9	1.5	1.3	1.4	1.5	1.6	2	2	2.2	1.8	1.8	1.3	4.1	1.6	1.1	2.1	1.7	5.1	1.3	0.95	2.8	1.6
Copper	1.3	1.5	2.7	1.3	1.4	1.3	1.5	1.2	2.1	2.1	2.2	1.5	1.5	1.1	6.4	2.3	1.3	2.8	2.4	5.6	2	1.5	4.4	2.4
Lead	2.2	2.5	2.5	2.4	2.3	2.2	2.2	2.4	2.3	2.3	2.9	2.4	2.4	2.1	5.6	2.6	1.6	2.9	2.3	5.4	2.3	1.8	3.8	2.5
Mercury	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.03	<0.02	<0.02	0.02	0.03
Molybdenum	0.41	0.45	0.64	0.3	0.43	0.37	0.35	0.39	0.4	0.4	0.47	0.38	0.38	0.33	0.53	0.51	0.44	0.39	0.36	0.47	0.57	0.33	0.44	0.57
Nickel	3.9	4.3	6.2	3.8	3.8	4.2	4.4	4.7	5.1	5.1	5.5	4.2	4.2	3.7	11	5.5	3.1	5.5	4.3	12	5.5	3.2	7.8	5
Selenium	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	0.08	<0.08	<0.08	0.08	0.22	<0.08	0.08	0.09	<0.08	0.22	<0.08	<0.08	0.11	0.08
Zinc	18	13	15	13	8.9	14	11	18	11	11	13	15	15	17	26	13	8.9	14	13	22	10	9	19	12
CEC	3.31	4.2	8.34	4.65	6.36	3.53	2.63	3.66	6.7	6.7	10.5	5.91	5.91	3.58	22.9	9.71	7.59	11.5	13	22.8	7.56	7.76	16.3	10.3

EC	0.06	0.07	0.1	0.08	0.08	0.07	0.06	0.17	0.08	0.08	0.11	0.06	0.06	0.05	0.21	0.09	0.09	0.1	0.1	0.14	0.11	0.07	0.15	0.12
OM	1.83	2.29	3.68	2.51	3.65	1.77	1.23	2.31	2.26	2.26	3.47	2.49	2.49	2.23	6.97	3.38	3.07	3.81	3.88	5.2	3.71	3.22	4.36	5.16
Gravel	0.21	0.8	0.2	0.1	0.21	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.3	0.2	0.5	0.3	1.3	0.5	0.1	0.6	2.5	0.81
Sand	91.8	90.8	91.6	90.9	88.5	91	88.8	91.8	90.9	90.9	85.6	90.1	90.1	93.3	37.2	86.4	88.1	78.1	84.7	49.6	85.5	90	67.7	84.7
Silt	6.5	5.8	5.9	6.6	8.2	5.7	8	4.1	5	5	9.3	7.4	7.4	4.2	31	6.8	7.1	9.3	7.6	21.7	8.1	6.7	16.1	7.3
Clay	1.6	3.3	2.5	2.5	3.3	3.3	3.2	4.1	4.2	4.2	5.1	2.5	2.5	2.5	31.9	6.8	4.8	12.7	7.6	28.7	6.5	3.3	16.1	8.1
Phosphorus	9.1	6.3	11	11	8.5	8	10	14	6.1	6.1	8.8	15	15	21	6.4	5.2	2.8	13	5.3	4.7	8	5.7	4	9.2
pH	5.8	6.2	6.4	6.4	5.6	6.3	6.7	5.6	7.3	7.3	7.2	6.6	6.6	5.2	7	6.7	6.6	6.7	7	7	6.5	6.9	7.3	6.6
Moisture	1.36	1.62	3.83	1.89	2.85	2.07	1.67	1.29	2.05	2.05	3.46	9.13	9.13	10.76	10.44	4.65	2.77	5.11	4.68	9.2	4.18	3.11	7.91	6.91
Nitrogen	0.04	0.05	0.11	0.06	0.06	0.05	0.04	0.06	0.06	0.06	0.1	0.08	0.08	0.05	0.25	0.1	0.08	0.14	0.13	0.19	0.1	0.11	0.13	0.13
K	30	31	42	44	45	37	44	36	39	39	40	48	48	38	130	53	53	81	64	84	59	46	110	78

Table 5: Descriptive statistics (after correction for normal distribution) for pin cherry and blueberry soil and fruits.

Type	Variables	Total N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis

		Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Std. Error	Statistic	Std. Error
Pin cherry soil	Arsenic	26	0.89	2.60	1.52	0.09	0.44	0.73	0.47	0.20	0.92
	Molybdenum	26	0.30	0.64	0.43	0.02	0.08	0.85	0.47	0.33	0.92
	Zinc	26	8.90	26.00	14.16	0.86	4.20	1.14	0.47	1.54	0.92
	Cadmium	26	-1.70	-1.05	-1.48	0.03	0.16	0.94	0.47	1.35	0.92
	Chromium	26	0.46	1.18	0.76	0.03	0.16	0.91	0.47	2.23	0.92
	Cobalt	26	-0.02	0.71	0.24	0.03	0.16	1.30	0.47	2.34	0.92
	Copper	26	0.04	0.81	0.30	0.04	0.21	1.14	0.47	0.79	0.92
	Lead	26	0.20	0.75	0.41	0.03	0.12	1.66	0.47	3.28	0.92
	Mercury	26	-1.70	-1.52	-1.68	0.01	0.05	3.22	0.47	9.12	0.92
	Nickel	26	0.49	1.08	0.69	0.03	0.14	1.34	0.47	1.99	0.92
	Selenium	26	-1.10	-0.66	-1.05	0.03	0.13	2.96	0.47	7.79	0.92
	C1 Dibenzothiophene	26	4.33	813.18	289.92	47.59	223.20	1.02	0.49	0.53	0.95
	C1 Chrysene	26	342.56	4512.42	2141.56	257.78	1209.09	0.48	0.49	-0.66	0.95
	C2 Chrysene	26	966.52	16050.99	7466.87	858.70	4027.67	0.28	0.49	-0.19	0.95
	C2 Naphthalene	26	0.69	1026.19	463.56	66.50	311.89	0.53	0.49	-0.96	0.95
	C2 Phenanthrene	26	299.64	1787.48	783.80	83.92	393.64	0.91	0.49	0.49	0.95
	C3 Phenanthrene	26	356.64	2466.17	1252.79	108.39	508.40	0.48	0.49	0.69	0.95

	C4 Phenanthrene	26	317.97	2387.95	1216.01	94.62	443.81	0.23	0.49	1.61	0.95
	C1 Fluorene	26	-0.78	2.23	0.96	0.25	1.19	-0.43	0.49	-1.71	0.95
	C2 Dibenzothiophene	26	2.35	3.23	2.69	0.05	0.24	0.44	0.49	-0.41	0.95
	C2 Fluorene	26	2.18	3.10	2.57	0.05	0.23	0.67	0.49	0.42	0.95
	C3 Dibenzothiophene	26	1.97	3.11	2.52	0.06	0.29	-0.10	0.49	0.13	0.95
	C3 Fluorene	26	2.47	3.47	2.89	0.05	0.23	0.95	0.49	1.23	0.95
	C4 Dibenzothiophene	26	2.90	4.04	3.43	0.06	0.30	0.18	0.49	-0.19	0.95
	C4 Fluorene	26	2.35	3.26	2.65	0.05	0.23	1.10	0.49	1.37	0.95
	Dibenzothiophene	26	0.59	2.40	1.69	0.10	0.48	-0.55	0.49	0.26	0.95
	C3 Chrysene	26	2.23	3.15	2.59	0.05	0.23	0.28	0.49	0.45	0.95
	C3 Naphthalene	26	2.25	3.15	2.64	0.04	0.21	0.39	0.49	0.86	0.95
	C4 Chrysene	26	1.96	3.11	2.51	0.06	0.27	0.06	0.49	0.45	0.95
	C4 Naphthalene (Butyl)	26	1.99	2.96	2.50	0.05	0.22	-0.57	0.49	1.25	0.95
	Retene	26	1.88	3.68	2.75	0.09	0.44	0.35	0.49	-0.11	0.95
	Total APAHs	26	3.99	4.65	4.32	0.04	0.18	0.28	0.49	-0.79	0.95
	Anthracene	26	7.22	86.89	39.01	4.65	22.80	0.90	0.47	0.02	0.92

	Benz[a]anthracene	26	21.39	286.02	101.74	15.24	74.68	1.02	0.47	0.46	0.92
	Benzo[a]pyrene	26	18.00	308.82	123.25	19.04	93.29	0.84	0.47	-0.42	0.92
	Benzo[g,h,i]perylene	26	14.73	447.76	181.54	22.13	108.40	0.54	0.47	0.20	0.92
	Benzo[k]fluoranthene	26	7.53	174.28	61.13	7.77	38.08	1.20	0.47	1.94	0.92
	Dibenzo[a,h]anthracene	26	0.13	102.25	43.52	6.64	32.51	0.43	0.47	-1.12	0.92
	Indeno[1,2,3-c,d]pyrene	26	10.22	206.11	84.47	10.49	51.38	0.95	0.47	0.64	0.92
	Pyrene	26	17.11	322.89	134.97	18.54	90.82	0.60	0.47	-0.69	0.92
	Total PAH	26	271.14	2451.76	1052.34	102.10	500.21	1.03	0.47	1.40	0.92
	Acenaphthene	26	0.05	2.37	1.46	0.13	0.65	-0.62	0.47	-0.51	0.92
	Acenaphthylene	26	-0.77	2.30	1.06	0.16	0.78	-0.67	0.47	0.73	0.92
	Benzo[b]fluoranthene	26	1.36	2.62	2.02	0.05	0.26	-0.30	0.47	1.53	0.92
	Fluoranthene	26	0.95	2.26	1.70	0.06	0.31	0.07	0.47	0.42	0.92
	EC	26	0.05	0.21	0.10	0.01	0.04	1.43	0.47	2.07	0.92
	OM	26	1.23	6.97	3.22	0.26	1.30	1.12	0.47	1.73	0.92
	OC	26	0.71	4.04	1.87	0.15	0.75	1.12	0.47	1.73	0.92

	Phosphorus	26	2.80	21.00	8.93	0.87	4.27	1.09	0.47	1.30	0.92
	pH	26	5.20	7.30	6.56	0.12	0.56	-0.81	0.47	0.28	0.92
	Moisture	26	1.29	10.76	4.67	0.64	3.14	0.78	0.47	-0.84	0.92
	Nitrogen	26	0.04	0.25	0.09	0.01	0.05	1.54	0.47	2.91	0.92
	CEC	26	0.42	1.36	0.86	0.05	0.26	0.30	0.47	-0.40	0.92
	Gravel	26	-1.00	0.40	-0.60	0.09	0.44	0.78	0.47	-0.59	0.92
	Sand	26	1.58	1.97	1.92	0.02	0.09	-2.97	0.47	8.76	0.92
	Silt	26	0.61	1.49	0.89	0.04	0.20	1.61	0.47	3.00	0.92
	Clay	26	0.20	1.50	0.70	0.07	0.34	1.10	0.47	0.69	0.92
	Total K	26	1.48	2.11	1.71	0.03	0.17	1.00	0.47	0.47	0.92
Pin cherry fruits	Boron	26	4.20	24.00	10.75	0.97	4.93	0.81	0.46	0.89	0.89
	Cadmium	26	0.00	0.00	0.00	0.00	0.00	-	-	-	-
	Cobalt	26	0.00	0.01	0.00	0.00	0.00	1.23	0.46	1.63	0.89
	Iron	26	4.40	9.50	6.67	0.28	1.43	0.12	0.46	-1.11	0.89
	Lead	26	0.00	0.00	0.00	0.00	0.00	-	-	-	-
	Nickel	26	0.05	0.12	0.07	0.00	0.02	0.78	0.46	0.09	0.89
	Zinc	26	1.90	3.80	2.92	0.10	0.50	-0.21	0.46	-0.33	0.89
	Arsenic	26	-3.30	-2.64	-3.05	0.05	0.25	0.13	0.46	-1.79	0.89
	Chromium	26	0.00	0.01	0.00	0.00	0.00	0.35	0.46	-0.33	0.89

	Copper	26	-0.04	0.51	0.18	0.03	0.13	0.49	0.46	0.59	0.89
	Magnesium	26	2.30	2.72	2.51	0.02	0.09	-0.22	0.46	1.32	0.89
	Mercury	26	-4.30	-3.33	-3.97	0.07	0.35	0.61	0.46	-0.92	0.89
	Molybdenum	26	-2.34	-1.33	-1.76	0.06	0.30	-0.10	0.46	-1.01	0.89
	Selenium	26	-2.60	-2.01	-2.58	0.02	0.12	5.10	0.46	26.00	0.89
	C1 Chrysene	26	0.29	0.34	0.31	0.01	0.02	-0.02	1.01	-1.07	2.62
	C1 Dibenzothiophene	26	0.27	0.50	0.43	0.05	0.11	-1.91	1.01	3.68	2.62
	C1 Fluorene	26	-1.69	0.22	-0.45	0.43	0.86	-1.58	1.01	2.46	2.62
	C2 Chrysene	26	0.65	0.77	0.72	0.03	0.06	-0.42	1.01	-3.01	2.62
	C2 Dibenzothiophene	26	0.06	0.97	0.38	0.20	0.41	1.61	1.01	2.70	2.62
	C2 Fluorene	26	0.31	0.77	0.63	0.11	0.21	-1.83	1.01	3.43	2.62
	C2 Naphthalene	26	0.10	0.49	0.24	0.09	0.18	1.63	1.01	2.78	2.62
	C2 Phenanthrene	26	0.15	0.48	0.32	0.07	0.13	-0.22	1.01	1.45	2.62
	C3 Chrysene	26	0.20	0.24	0.23	0.01	0.02	-1.58	1.01	2.28	2.62
	C3 Dibenzothiophene	26	0.10	1.06	0.42	0.22	0.44	1.69	1.01	2.82	2.62
	C3 Fluorene	26	-1.20	0.78	-0.07	0.42	0.85	-0.86	1.01	0.61	2.62
	C3 Naphthalene	26	0.24	0.39	0.34	0.03	0.07	-1.12	1.01	0.07	2.62

	C3 Phenanthrene	26	-1.99	0.41	-0.30	0.57	1.14	-1.88	1.01	3.56	2.62
	C4 Chrysene	26	0.04	0.04	0.04	0.00	0.00	-2.00	1.01	4.00	2.62
	C4 Dibenzothiophene	26	1.11	1.66	1.51	0.13	0.27	-1.96	1.01	3.86	2.62
	C4 Fluorene	26	-2.08	0.60	-0.47	0.57	1.15	-1.24	1.01	1.96	2.62
	C4 Naphthalene (Butyl)	26	0.27	0.29	0.28	0.00	0.01	-0.12	1.01	-2.87	2.62
	C4 Phenanthrene	26	-1.04	-0.20	-0.52	0.18	0.37	-1.32	1.01	1.65	2.62
	Dibenzothiophene	26	-1.36	-0.55	-0.94	0.20	0.40	-0.12	1.01	-4.63	2.62
	Retene	26	-1.53	-0.68	-1.00	0.18	0.37	-1.49	1.01	2.80	2.62
	Total APAHs	26	1.11	1.89	1.40	0.17	0.35	1.38	1.01	1.85	2.62
	Acenaphthene	26	-1.83	-0.44	-1.10	0.06	0.28	0.79	0.46	3.42	0.90
	Acenaphthylene	26	0.01	0.02	0.02	0.00	0.01	-2.78	0.46	6.61	0.90
	Anthracene	26	0.00	0.02	0.00	0.00	0.00	2.14	0.46	4.62	0.90
	Benz[a]anthracene	26	0.00	0.02	0.01	0.00	0.01	0.78	0.46	-1.18	0.90
	Benzo[a]pyrene	26	0.00	0.02	0.00	0.00	0.01	2.51	0.46	4.73	0.90
	Benzo[b]fluoranthene	26	0.00	0.03	0.02	0.00	0.01	-1.10	0.46	4.63	0.90
	Benzo[g,h,i]perylene	26	0.00	0.01	0.00	0.00	0.00	2.88	0.46	7.97	0.90

	Benzo[k]fluoranthene	26	0.00	0.02	0.01	0.00	0.01	1.34	0.46	0.27	0.90
	Fluoranthene	26	-1.81	-0.84	-1.32	0.04	0.18	-0.92	0.46	4.21	0.90
	Indeno[1,2,3-c,d]pyrene	26	0.00	0.04	0.00	0.00	0.01	5.00	0.46	25.00	0.90
	Pyrene	26	-2.16	-0.60	-1.22	0.07	0.34	-0.19	0.46	1.25	0.90
	Total PAHs	26	-0.29	-0.06	-0.18	0.01	0.05	0.61	0.46	0.60	0.90
	Dibenzo[a,h]anthracene	26	0.05	0.05	0.05	0.00	0.00	-	-	-	-
	TAnC	26	6.23	24.20	15.49	0.94	4.80	-0.27	0.46	-1.04	0.89
	TPC	26	13.09	32.28	21.42	0.92	4.69	0.33	0.46	-0.23	0.89
	Vitamin C	26	72.75	273.38	153.61	8.50	43.33	0.70	0.46	0.90	0.89
	Fruit pH	26	3.37	4.17	3.68	0.04	0.19	0.25	0.46	0.58	0.89
	TAA	26	0.00	1.60	1.12	0.07	0.36	-1.19	0.46	2.26	0.89
	TAC	26	0.71	1.22	0.94	0.02	0.12	0.08	0.46	0.44	0.89
	Water Content	26	0.00	0.11	0.06	0.01	0.03	0.45	0.46	0.17	0.89
Blueberry soil	Arsenic	15	0.70	2.10	1.37	0.14	0.45	-0.08	0.69	-0.84	1.33
	Cadmium	15	0.03	0.12	0.08	0.01	0.03	-0.05	0.69	-1.52	1.33
	Chromium	15	4.00	14.00	8.79	1.15	3.63	-0.07	0.69	-1.53	1.33
	Cobalt	15	1.10	3.40	2.28	0.28	0.89	-0.08	0.69	-1.84	1.33

	Copper	15	0.95	4.60	2.80	0.42	1.32	-0.11	0.69	-1.51	1.33
	Lead	15	2.10	4.50	3.06	0.27	0.85	0.54	0.69	-0.91	1.33
	Mercury	15	0.02	0.04	0.03	0.00	0.01	1.04	0.69	0.44	1.33
	Molybdenum	15	0.23	0.74	0.50	0.06	0.18	-0.05	0.69	-1.25	1.33
	Nickel	15	2.90	9.40	6.04	0.71	2.25	-0.05	0.69	-1.40	1.33
	Selenium	15	0.08	0.45	0.22	0.04	0.13	0.42	0.69	-0.84	1.33
	Zinc	15	1.04	1.53	1.20	0.04	0.14	1.35	0.69	2.89	1.33
	C1 Dibenzothiophene	15	4.33	365.44	196.63	44.24	139.90	-0.01	0.69	-1.96	1.33
	C1 Fluorene	15	0.39	73.66	38.40	7.96	25.19	-0.16	0.69	-1.51	1.33
	C2 Dibenzothiophene	15	163.30	999.48	465.27	75.21	237.84	1.10	0.69	2.24	1.33
	C2 Fluorene	15	84.87	690.73	296.45	60.09	190.01	1.28	0.69	1.05	1.33
	C3 Dibenzothiophene	15	102.09	501.33	290.81	42.21	133.48	0.09	0.69	-1.16	1.33
	C3 Fluorene	15	220.46	1445.63	652.77	118.22	373.84	1.06	0.69	1.06	1.33
	C4 Dibenzothiophene	15	777.67	5103.21	2205.92	428.31	1354.45	1.13	0.69	1.02	1.33
	C4 Fluorene	15	121.79	809.76	366.50	67.40	213.13	1.05	0.69	0.75	1.33
	Dibenzothiophene	15	5.80	104.67	51.06	11.42	36.11	0.14	0.69	-1.55	1.33

	C1 Chrysene	15	342.56	2452.79	913.52	212.87	673.16	1.43	0.69	2.07	1.33
	C2 Chrysene	15	966.52	8086.44	3415.98	715.73	2263.32	0.98	0.69	0.52	1.33
	C2 Phenanthrene	15	242.75	1323.60	537.93	96.10	303.91	2.20	0.69	5.69	1.33
	C3 Chrysene	15	96.67	732.18	278.86	59.15	187.04	1.79	0.69	3.67	1.33
	C3 Naphthalene	15	108.11	850.93	341.28	74.55	235.75	1.38	0.69	1.35	1.33
	C3 Phenanthrene	15	285.30	1474.49	692.23	102.92	325.45	1.57	0.69	3.65	1.33
	C4 Phenanthrene	15	213.51	1365.24	700.85	126.69	400.61	0.42	0.69	-1.33	1.33
	Retene	15	73.44	815.96	306.69	84.50	267.21	1.00	0.69	-0.42	1.33
	Total APAHs	15	5540.27	22506.38	12843.25	1605.32	5076.47	0.46	0.69	0.08	1.33
	C2 Naphthalene	15	2.21	3.24	2.63	0.11	0.35	0.69	0.69	-0.88	1.33
	C4 Chrysene	15	1.66	2.60	2.15	0.10	0.32	0.03	0.69	-1.05	1.33
	C4 Naphthalene (Butyl)	15	2.06	2.98	2.43	0.09	0.28	0.61	0.69	0.26	1.33
	Acenaphthene	15	0.79	2.24	1.18	0.15	0.48	1.68	0.69	1.96	1.33
	Acenaphthylene	15	0.90	2.36	1.29	0.15	0.49	1.63	0.69	1.83	1.33
	Anthracene	15	1.26	2.68	1.70	0.12	0.39	1.87	0.69	4.55	1.33
	Benz[a]anthracene	15	1.36	3.15	2.13	0.14	0.44	0.89	0.69	3.76	1.33
	Benzo[a]pyrene	15	1.04	3.38	2.13	0.20	0.62	0.20	0.69	1.90	1.33

	Benzo[b]fluoranthene	15	1.15	2.95	1.91	0.15	0.49	0.60	0.69	1.88	1.33
	Benzo[g,h,i]perylene	15	0.95	3.12	1.99	0.19	0.60	-0.10	0.69	1.22	1.33
	Benzo[k]fluoranthene	15	0.88	2.57	1.57	0.15	0.46	0.80	0.69	2.08	1.33
	Dibenzo[a,h]anthracene	15	-0.88	2.72	1.54	0.29	0.92	-2.22	0.69	6.76	1.33
	Fluoranthene	15	1.71	2.90	1.93	0.11	0.35	2.73	0.69	7.90	1.33
	Indeno[1,2,3-c,d]pyrene	15	0.85	2.70	1.61	0.16	0.50	0.74	0.69	2.31	1.33
	Pyrene	15	1.96	3.29	2.31	0.12	0.37	2.38	0.69	6.53	1.33
	Total PAHs	15	2.54	4.04	3.02	0.13	0.40	2.02	0.69	5.43	1.33
	CEC	15	3.58	47.40	29.43	5.64	17.82	-0.50	0.69	-1.60	1.33
	EC	15	0.04	0.19	0.11	0.01	0.05	-0.07	0.69	-0.55	1.33
	OM	15	1.98	29.40	17.30	3.46	10.94	-0.40	0.69	-1.70	1.33
	OC	15	1.15	17.05	10.03	2.01	6.35	-0.40	0.69	-1.70	1.33
	Gravel	15	0.00	1.50	0.37	0.14	0.45	1.93	0.69	4.31	1.33
	Sand	15	34.80	93.30	62.42	7.10	22.44	0.22	0.69	-1.50	1.33
	Silt	15	4.20	36.60	20.20	3.65	11.55	-0.25	0.69	-1.30	1.33
	Clay	15	1.60	32.60	17.35	3.57	11.28	-0.15	0.69	-1.62	1.33

	Total K	15	34.00	81.00	60.20	5.42	17.13	-0.45	0.69	-1.20	1.33
	pH	15	4.60	5.70	4.99	0.10	0.32	1.07	0.69	1.90	1.33
	Moisture	15	8.59	65.93	38.15	6.96	22.02	-0.15	0.69	-1.55	1.33
	N	15	0.03	0.47	0.30	0.05	0.16	-0.80	0.69	-0.64	1.33
	Total P	15	0.79	1.32	0.99	0.06	0.18	1.07	0.69	-0.02	1.33
Blueberry fruits	Arsenic	15	0.00	0.01	0.00	0.00	0.00	0.55	0.58	-1.00	1.12
	Boron	15	0.93	2.30	1.58	0.11	0.44	0.20	0.58	-1.49	1.12
	Magnesium	15	51.00	110.00	90.00	3.76	14.58	-1.17	0.58	2.81	1.12
	Mercury	15	0.00	0.00	0.00	0.00	0.00	0.90	0.58	0.55	1.12
	Nickel	15	0.03	0.16	0.11	0.01	0.03	-0.71	0.58	1.77	1.12
	Selenium	15	0.00	0.00	0.00	0.00	0.00	-	-	-	-
	Cadmium	15	-3.30	-2.29	-2.99	0.09	0.36	0.56	0.58	-1.25	1.12
	Chromium	15	-1.92	-0.74	-1.70	0.08	0.29	2.85	0.58	8.84	1.12
	Cobalt	15	-3.27	-1.85	-2.34	0.11	0.41	-0.68	0.58	0.18	1.12
	Copper	15	-0.34	0.08	-0.14	0.02	0.09	0.24	0.58	3.53	1.12
	Iron	15	0.53	1.40	0.94	0.06	0.22	0.42	0.58	0.62	1.12
	Lead	15	-3.00	-1.89	-2.82	0.08	0.32	2.09	0.58	4.84	1.12
	Molybdenum	15	-2.68	-1.05	-1.89	0.16	0.64	0.03	0.58	-1.79	1.12
	Zinc	15	-0.15	0.58	0.25	0.04	0.15	-0.63	0.58	4.49	1.12

	C2 Chrysene	15	0.66	1.75	1.10	0.21	0.48	0.54	0.91	-1.91	2.00
	C3 Chrysene	15	0.04	0.16	0.09	0.02	0.04	1.28	0.91	2.90	2.00
	C4 Fluorene	15	-0.70	0.24	-0.37	0.18	0.39	1.18	0.91	0.41	2.00
	Retene	15	0.02	0.17	0.08	0.03	0.06	0.53	0.91	-1.09	2.00
	C1 Chrysene	15	-0.79	-0.30	-0.58	0.09	0.21	0.46	0.91	-1.10	2.00
	C1 Dibenzothiophene	15	-2.87	0.08	-1.16	0.48	1.08	-0.98	0.91	1.95	2.00
	C1 Fluorene	15	-0.99	0.08	-0.50	0.17	0.38	0.52	0.91	1.64	2.00
	C2 Dibenzothiophene	15	-2.28	0.83	-0.61	0.51	1.14	-0.47	0.91	1.16	2.00
	C2 Fluorene	15	-1.01	0.43	-0.42	0.24	0.53	1.05	0.91	2.10	2.00
	C2 Naphthalene	15	-0.20	0.55	0.18	0.13	0.29	-0.10	0.91	-0.91	2.00
	C2 Phenanthrene	15	-0.73	0.54	-0.36	0.23	0.51	1.97	0.91	3.99	2.00
	C3 Dibenzothiophene	15	-2.57	0.88	-0.74	0.55	1.24	-0.36	0.91	1.57	2.00
	C3 Fluorene	15	-0.99	0.60	-0.08	0.26	0.58	-0.86	0.91	1.86	2.00
	C3 Naphthalene	15	-2.35	-0.15	-0.88	0.42	0.93	-1.26	0.91	0.46	2.00
	C3 Phenanthrene	15	-1.84	0.58	-0.17	0.43	0.95	-1.97	0.91	4.20	2.00
	C4 Chrysene	15	-3.02	-1.02	-2.39	0.41	0.91	1.09	0.91	-0.58	2.00

	C4 Dibenzothiophene	15	-0.71	1.38	0.02	0.38	0.84	1.36	0.91	1.56	2.00
	C4 Naphthalene (Butyl)	15	-2.41	-0.37	-1.23	0.35	0.77	-0.87	0.91	0.95	2.00
	C4 Phenanthrene	15	-1.87	0.04	-0.97	0.40	0.90	0.42	0.91	-3.05	2.00
	Dibenzothiophene	15	-2.32	-0.85	-1.55	0.24	0.54	-0.31	0.91	0.55	2.00
	Total APAHs	15	0.76	1.71	1.05	0.17	0.39	1.65	0.91	2.92	2.00
	Acenaphthene	15	-1.17	-0.22	-1.11	0.06	0.25	3.87	0.58	15.00	1.12
	Acenaphthylene	15	-1.55	-0.24	-1.15	0.08	0.30	2.34	0.58	6.85	1.12
	Anthracene	15	-1.36	-0.50	-1.30	0.06	0.22	3.85	0.58	14.89	1.12
	Benz[a]anthracene	15	-1.98	0.11	-1.26	0.12	0.46	1.75	0.58	6.42	1.12
	Benzo[a]pyrene	15	-1.86	0.17	-1.22	0.11	0.43	2.47	0.58	8.99	1.12
	Benzo[b]fluoranthene	15	-3.19	0.20	-1.67	0.20	0.77	0.09	0.58	2.69	1.12
	Benzo[g,h,i]perylene	15	-2.48	0.12	-1.48	0.14	0.53	1.68	0.58	7.03	1.12
	Benzo[k]fluoranthene	15	-2.68	0.19	-1.40	0.15	0.58	0.70	0.58	5.46	1.12
	Dibenzo[a,h]anthracene	15	-2.29	0.11	-1.31	0.12	0.46	1.58	0.58	8.19	1.12
	Fluoranthene	15	-2.81	0.07	-1.40	0.16	0.64	-0.35	0.58	3.09	1.12

	Indeno[1,2,3-c,d]pyrene	15	-2.01	0.16	-0.94	0.11	0.41	0.15	0.58	7.01	1.12
	Pyrene	15	-1.44	0.11	-1.17	0.10	0.39	2.86	0.58	8.78	1.12
	Total PAHs	15	-0.36	1.14	-0.12	0.09	0.35	3.71	0.58	14.17	1.12
	TAnC	15	1.16	40.64	12.67	2.50	9.68	1.74	0.58	4.36	1.12
	TAC	15	4.00	10.92	6.94	0.53	2.04	0.75	0.58	0.36	1.12
	TPC	15	7.97	14.75	10.58	0.46	1.80	0.54	0.58	0.55	1.12
	Vitamin C	15	88.66	161.72	117.81	6.78	26.25	0.51	0.58	-1.45	1.12
	Fruit pH	15	3.23	3.48	3.36	0.02	0.06	0.03	0.58	0.45	1.12
	TAA	15	0.00	1.64	1.15	0.11	0.42	-1.41	0.58	3.08	1.12
	Water Content	15	-0.47	-0.40	-0.44	0.00	0.02	0.67	0.58	2.78	1.12

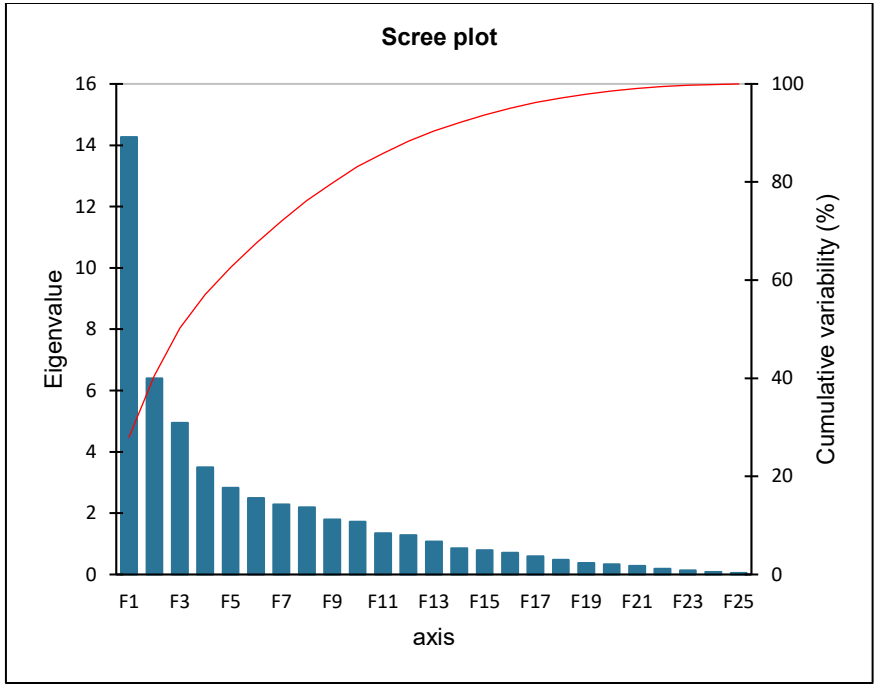

Figure 1: PCA scree plot for pin cherry fruits (SS1, SS2, RS1)

Table 6: PCA factor loadings for pin cherry fruits (SS1, SS2, RS1)

	PC1	PC2	PC3	PC4
B	0.490	0.455	-0.154	-0.341
Co	0.582	0.531	0.142	-0.018
Fe	-0.438	0.163	0.226	-0.200
Ni	0.409	0.159	0.116	0.125
Zn	0.544	0.186	-0.385	0.137
APAH1	-0.781	0.226	-0.137	-0.370
APAH2	-0.753	0.478	0.107	0.250

APAH3	0.769	-0.259	-0.108	-0.190
APAH4	-0.596	0.118	0.017	-0.457
APAH5	0.856	-0.174	-0.002	-0.221
APAH6	-0.669	0.508	0.277	0.264
APAH7	-0.115	0.150	-0.279	0.330
APAH8	-0.557	-0.093	0.009	-0.565
APAH9	-0.354	-0.034	0.163	-0.445
APAH10	0.815	-0.105	-0.045	-0.253
APAH11	0.794	-0.250	0.039	-0.247
APAH12	-0.781	0.182	-0.399	-0.065
APAH13	0.345	-0.102	0.264	0.670
APAH14	-0.403	-0.262	-0.597	-0.230
APAH15	-0.636	0.508	0.087	0.229
APAH17	-0.701	0.468	0.068	-0.071
APAH18	0.811	0.125	-0.042	0.245
APAH19	0.270	-0.376	-0.475	-0.476
APAH20	0.717	-0.194	0.291	-0.117
Total APAHs	0.863	-0.271	0.084	-0.126
PAH1	-0.030	0.484	0.685	-0.282
PAH2	-0.095	0.290	0.253	-0.272
PAH3	0.228	0.237	0.573	0.204
PAH4	0.315	0.172	0.498	0.024
PAH5	0.060	-0.539	0.219	-0.204
PAH6	-0.305	-0.435	0.224	0.121
PAH7	0.547	-0.404	0.169	0.246
PAH8	0.517	-0.186	0.227	0.444
PAH10	-0.275	-0.407	0.092	0.140
PAH11	-0.312	-0.507	0.416	-0.164
PAH12	0.730	-0.184	0.066	-0.192
Total PAHs	0.409	0.153	0.335	-0.513
As	0.345	0.689	0.257	-0.119

Cr	-0.399	-0.002	-0.248	-0.056
Cu	-0.060	0.050	-0.181	-0.104
Mg	0.557	0.566	-0.304	-0.025
Hg	-0.708	-0.328	0.327	-0.091
Mo	-0.625	-0.223	0.400	0.049
Se	0.335	0.404	0.479	-0.047
TAnC	0.391	0.209	-0.489	0.179
TPC	0.007	0.260	-0.576	0.161
VitaminC	0.020	-0.661	-0.110	0.071
pH	0.624	0.580	0.084	-0.120
TAA	0.111	-0.076	0.719	-0.116
TAC	0.418	0.619	-0.236	0.037
WC	-0.422	-0.508	0.211	0.346

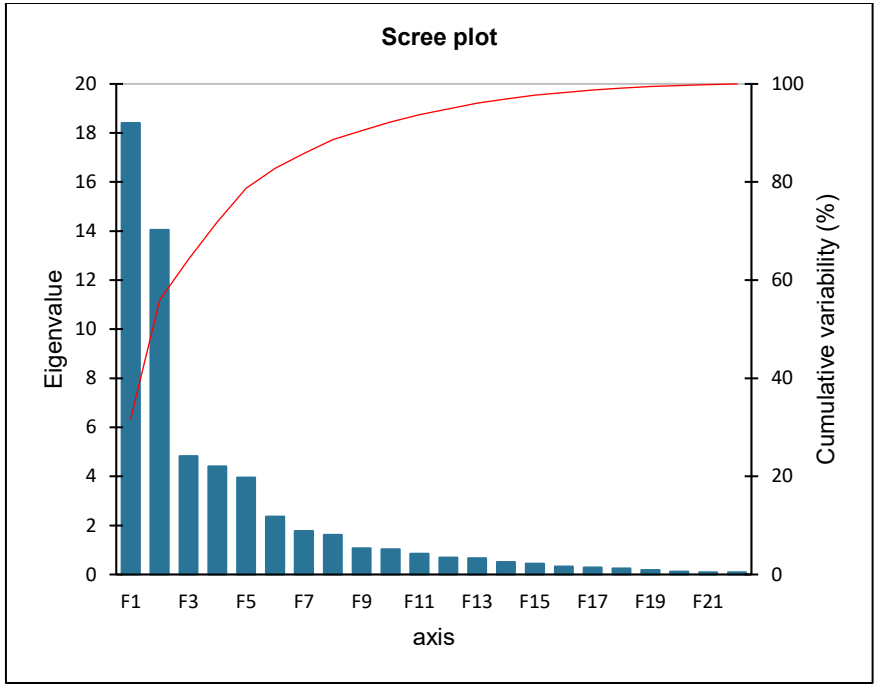

Figure 2: PCA scree plot for pin cherry soil (SS1, SS2, RS1)

Table 7: PCA factor loadings for pin cherry soil (SS1, SS2, RS1)

	PC1	PC2	PC3	PC4
APAH1	-0.216	0.902	-0.001	0.013
APAH10	-0.309	0.791	0.122	-0.127
APAH11	-0.334	0.745	-0.063	0.041
APAH12	-0.338	0.264	0.659	-0.094
APAH13	-0.530	0.665	0.109	0.083
APAH16	-0.697	0.258	-0.023	0.247
APAH19	-0.730	-0.123	0.016	0.235

PAH3	-0.164	0.579	0.385	-0.372
PAH4	0.004	0.715	0.323	-0.506
PAH5	-0.066	0.802	0.136	-0.488
PAH7	-0.358	0.733	-0.487	0.022
PAH8	-0.319	0.682	-0.294	-0.284
PAH9	-0.166	0.887	-0.009	-0.252
PAH11	-0.444	0.520	-0.632	0.033
PAH12	-0.151	0.649	0.120	-0.325
TotalPAH	-0.355	0.756	-0.287	-0.278
As	0.556	0.220	-0.598	0.314
Mo	0.478	0.136	0.173	0.103
Zn	0.700	-0.094	-0.041	0.248
EC	0.745	0.306	-0.015	0.123
OM	0.856	0.348	0.246	-0.067
OC	0.856	0.348	0.246	-0.067
Phosphorus	-0.175	-0.621	0.321	0.266
pH	0.284	0.638	-0.441	-0.140
Moisture	0.650	-0.066	0.330	-0.126
Nitrogen	0.886	0.354	0.127	-0.075
APAH2	-0.221	0.464	0.037	0.210
APAH3	0.032	0.594	0.353	0.611
APAH4	-0.316	0.506	0.092	0.707
APAH5	-0.019	0.574	0.301	0.652
APAH6	-0.067	0.481	0.214	0.692
APAH7	-0.087	0.517	0.335	0.693
APAH8	-0.558	0.261	-0.635	0.195
APAH9	0.083	0.909	0.205	0.066
APAH14	-0.544	0.464	0.076	0.165
APAH15	-0.519	0.458	0.378	0.045
APAH17	-0.533	0.295	-0.033	0.167
APAH18	-0.832	0.148	0.024	0.010

APAH20	-0.372	-0.386	0.427	-0.021
Total APAHs	-0.499	0.755	-0.036	0.227
PAH1	-0.199	-0.276	-0.484	0.066
PAH2	-0.180	-0.161	-0.393	0.176
PAH6	-0.412	0.663	-0.451	-0.110
PAH10	-0.281	0.127	-0.228	-0.311
Cd	0.837	0.104	0.263	0.151
Cr	0.816	-0.037	-0.243	0.298
Co	0.834	0.138	-0.345	0.253
Cu	0.855	0.411	-0.138	0.058
Pb	0.907	0.096	-0.203	0.207
Hg	0.488	0.075	0.060	-0.027
Ni	0.874	0.189	-0.254	0.196
Se	0.870	0.183	-0.175	0.064
CEC	0.780	0.505	0.118	-0.095
Gravel	0.486	0.450	0.226	-0.224
Sand	-0.891	-0.248	0.140	-0.019
Silt	0.829	0.284	-0.092	-0.047
Clay	0.840	0.416	-0.077	-0.124
K	0.776	0.419	0.124	-0.229

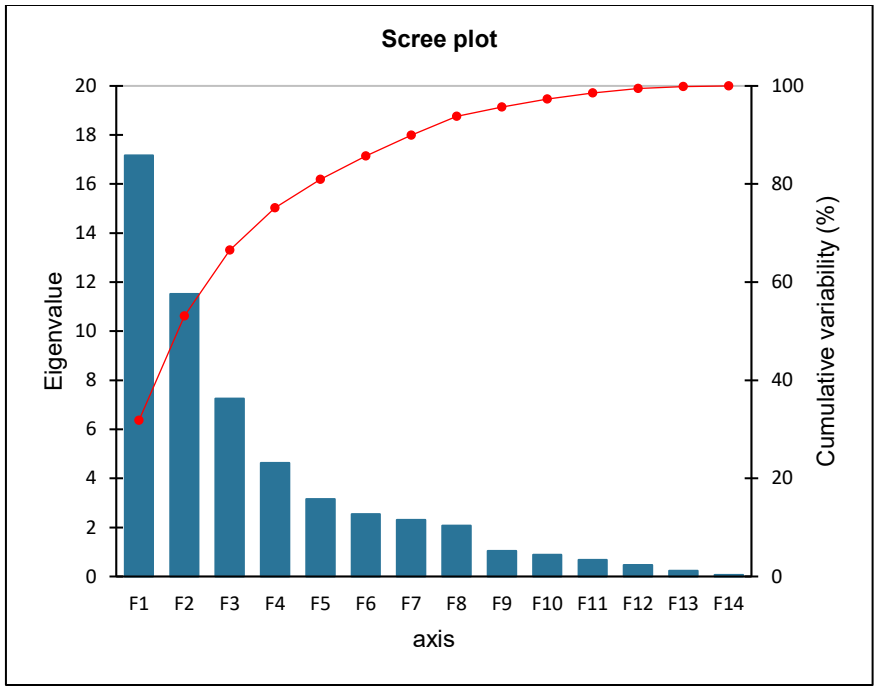

Figure 3: PCA scree plot for blueberry fruits (SS3, RS2)

Table 8: PCA factor loadings for blueberry fruits (SS3, RS2)

	PC1	PC2	PC3	PC4
APAH4	0.423	0.187	0.304	-0.027
APAH9	-0.083	-0.702	-0.090	-0.202
APAH16	-0.345	0.568	0.037	0.339
APAH20	0.079	0.628	-0.359	0.590
PAH1	0.986	0.056	-0.101	0.008
PAH2	0.985	0.015	-0.090	-0.003
PAH3	0.986	0.056	-0.105	0.001

PAH4	0.985	0.052	-0.097	0.004
PAH5	0.984	0.062	-0.103	0.005
PAH6	0.983	0.061	-0.100	0.008
PAH7	0.986	0.048	-0.104	-0.005
PAH8	0.988	0.047	-0.092	0.014
PAH9	0.989	0.049	-0.088	0.022
PAH10	0.983	0.039	-0.113	-0.019
PAH11	0.989	0.033	-0.106	-0.021
PAH12	0.977	0.117	-0.096	0.038
TotalPAHs	0.987	0.055	-0.100	0.005
As	0.174	-0.315	0.701	0.162
Bo	0.409	0.242	0.783	0.051
Mg	0.238	0.598	0.376	-0.513
Hg	-0.317	0.144	0.262	-0.465
Ni	-0.009	0.682	0.074	-0.441
APAH1	0.165	0.707	-0.061	-0.026
APAH2	-0.085	0.883	-0.110	-0.230
APAH3	-0.624	0.520	-0.064	0.124
APAH5	-0.202	0.864	-0.158	-0.243
APAH6	-0.581	0.606	-0.207	-0.086
APAH7	0.036	0.361	-0.652	0.367
APAH8	0.460	0.462	-0.005	0.393
APAH10	-0.171	0.866	-0.138	-0.166
APAH11	-0.830	0.373	-0.137	-0.069
APAH12	0.285	0.537	-0.339	0.307
APAH13	0.152	0.790	-0.227	-0.135
APAH14	-0.051	-0.248	0.315	0.816
APAH15	-0.151	0.869	-0.278	0.042
APAH17	0.173	0.658	-0.552	0.063
APAH18	0.271	0.419	0.071	0.724
APAH19	-0.653	0.589	0.068	0.003

Total APAHs	-0.007	0.903	-0.323	0.041
Cd	0.427	0.240	0.826	-0.054
Cr	-0.096	0.423	0.748	-0.124
Co	0.370	0.504	0.589	-0.017
Cu	0.164	0.556	0.644	-0.205
Fe	-0.293	0.491	0.000	0.165
Pb	-0.144	0.457	0.727	-0.079
Mo	-0.418	0.239	-0.554	0.120
Zn	0.158	0.611	0.601	-0.309
TAnC	-0.353	0.117	0.381	0.550
TAC	-0.107	-0.090	-0.655	-0.174
TPC	-0.347	0.050	0.339	0.744
VitaminC	0.298	0.145	0.236	0.407
pH	0.017	-0.009	-0.411	-0.053
TAA	0.341	-0.142	-0.370	-0.605
WC	-0.607	-0.288	-0.118	-0.158

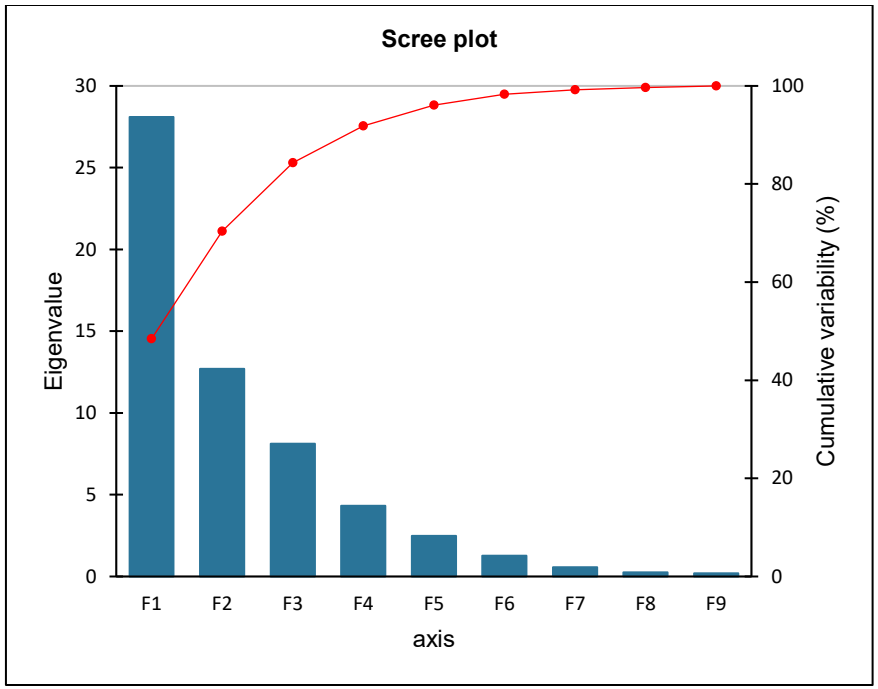

Figure 4: PCA scree plot for blueberry soil (SS3, RS2)

Table 9: PCA factor loadings for blueberry soil (SS3, RS2)

	PC1	PC2	PC3	PC4
APAH1	0.437	0.526	0.106	-0.667
APAH2	-0.226	0.859	0.018	-0.365
APAH3	-0.838	0.490	-0.056	-0.150
APAH4	-0.812	0.211	-0.041	-0.091
APAH5	-0.588	0.120	-0.086	-0.558
APAH6	-0.719	0.403	0.004	-0.081
APAH7	-0.771	0.453	-0.316	-0.219

APAH8	-0.828	0.251	-0.155	-0.178
APAH9	0.382	0.496	-0.109	-0.736
APAH10	0.416	0.540	0.596	-0.393
APAH11	0.529	0.603	0.499	-0.299
APAH13	0.201	0.521	0.798	-0.155
APAH14	-0.062	0.370	0.870	0.039
APAH15	-0.375	0.441	0.770	0.210
APAH16	-0.052	0.513	0.841	-0.076
APAH19	-0.717	0.168	0.575	0.287
APAH20	-0.839	-0.082	0.292	0.365
TotalAPAHs	-0.241	0.732	0.578	-0.233
CEC	0.935	0.215	-0.172	0.042
EC	0.909	0.075	-0.372	0.054
OM	0.952	0.279	-0.006	0.097
OC	0.952	0.279	-0.006	0.097
Gravel	0.565	0.224	-0.019	-0.127
Sand	-0.938	-0.297	-0.057	-0.142
Silt	0.898	0.385	0.086	0.079
Clay	0.950	0.196	0.026	0.202
K	0.664	0.232	-0.351	-0.557
pH	-0.865	-0.049	-0.257	0.344
Moisture	0.898	0.229	-0.168	0.076
N	0.954	0.193	0.015	-0.095
As	0.902	0.247	-0.178	0.237
Cd	0.891	0.251	-0.095	0.288
Cr	0.880	0.351	0.153	0.163
Co	0.891	0.291	-0.062	0.288
Cu	0.945	0.232	0.048	0.195
Pb	0.832	0.341	0.215	0.284
Hg	0.749	0.035	0.184	0.470
Mo	0.906	0.173	0.000	0.124

Ni	0.864	0.396	0.179	0.161
Se	0.852	0.363	0.251	0.211
APAH12	-0.482	0.360	0.749	0.153
APAH17	-0.615	0.162	0.662	0.067
APAH18	-0.442	0.408	0.770	-0.031
PAH1	-0.860	0.225	0.052	0.264
PAH2	-0.843	0.249	0.066	0.274
PAH3	-0.749	0.492	-0.184	0.226
PAH4	-0.483	0.717	-0.328	0.158
PAH5	-0.201	0.905	-0.326	0.120
PAH6	-0.297	0.835	-0.442	0.064
PAH7	-0.149	0.885	-0.419	0.064
PAH8	-0.315	0.821	-0.462	0.025
PAH9	0.034	0.693	-0.423	-0.107
PAH10	-0.774	0.479	-0.294	0.209
PAH11	-0.298	0.852	-0.410	0.094
PAH12	-0.608	0.663	-0.380	0.127
Total PAHs	-0.559	0.733	-0.343	0.145
P	-0.729	-0.539	0.394	-0.002
Zn	-0.387	0.507	0.005	0.761

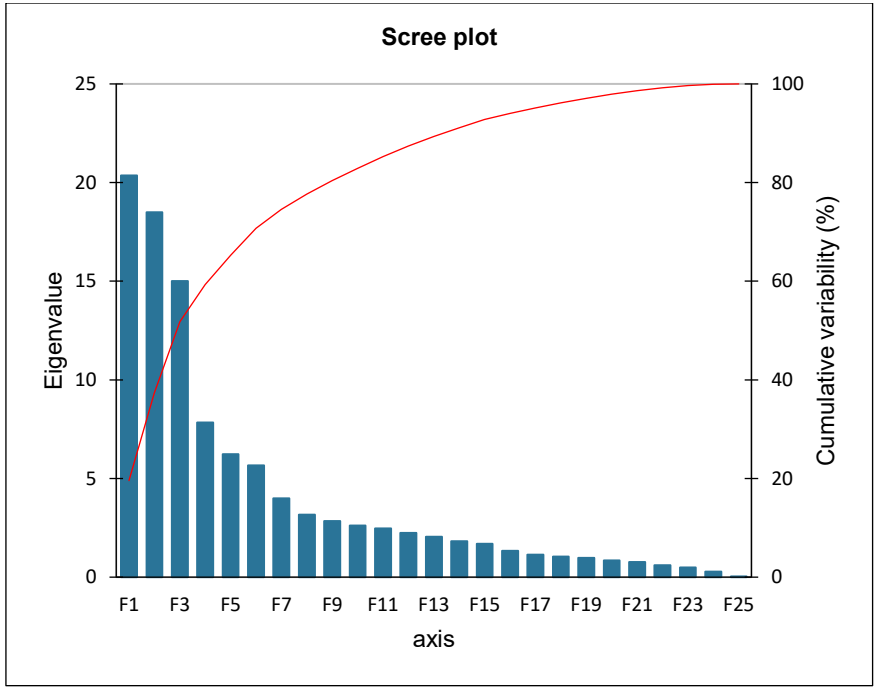

Figure 5: PCA scree plot for pin cherry fruits and soil (SS1, SS2, RS1)

Table 10: PCA factor loadings for pin cherry fruits and soil (SS1, SS2, RS1)

	PC1	PC2	PC3	PC4
FruitsB	0.046	-0.832	0.015	-0.137
FruitsCo	-0.199	-0.512	-0.324	-0.105
FruitsFe	0.336	0.104	0.336	0.080
FruitsNi	-0.087	-0.034	-0.686	-0.174
FruitsZn	-0.270	-0.446	-0.175	-0.512

FruitsAPAH1	0.534	0.251	0.589	-0.064
FruitsAPAH2	0.362	0.378	0.482	-0.225
FruitsAPAH3	-0.483	-0.408	-0.438	0.037
FruitsAPAH4	0.442	0.100	0.557	0.200
FruitsAPAH5	-0.476	-0.535	-0.452	0.097
FruitsAPAH6	0.348	0.317	0.420	-0.169
FruitsAPAH7	-0.035	0.014	0.220	-0.377
FruitsAPAH8	0.576	0.191	0.267	0.160
FruitsAPAH9	0.303	-0.006	0.419	0.417
FruitsAPAH10	-0.442	-0.601	-0.358	0.017
FruitsAPAH11	-0.508	-0.431	-0.408	0.197
FruitsAPAH12	0.373	0.432	0.491	-0.431
FruitsAPAH13	-0.190	-0.025	-0.356	-0.037
FruitsAPAH14	0.378	0.282	0.064	-0.425
FruitsAPAH15	0.275	0.323	0.408	-0.255
FruitsAPAH17	0.394	0.284	0.444	-0.202
FruitsAPAH18	-0.434	-0.579	-0.381	-0.163
FruitsAPAH19	-0.020	-0.172	-0.210	-0.140
FruitsAPAH20	-0.360	-0.319	-0.522	0.250
FruitsTotal APAHs	-0.537	-0.434	-0.532	0.201
FruitsPAH1	0.270	-0.271	0.076	0.282
FruitsPAH2	0.633	-0.288	-0.159	0.053
FruitsPAH3	-0.224	-0.142	-0.070	0.244
FruitsPAH4	-0.139	-0.139	-0.243	0.417
FruitsPAH5	0.312	-0.068	-0.258	0.447
FruitsPAH6	0.244	0.391	-0.144	0.057
FruitsPAH7	-0.374	-0.164	-0.365	0.257
FruitsPAH8	-0.487	-0.111	-0.275	0.315
FruitsPAH10	-0.055	0.489	0.081	-0.093

FruitsPAH11	0.080	0.404	0.042	0.423
FruitsPAH12	-0.382	-0.532	-0.315	0.271
FruitsTotal PAHs	-0.055	-0.481	-0.125	0.191
FruitsAs	-0.047	-0.454	-0.182	-0.058
FruitsCr	0.122	0.271	0.284	-0.459
FruitsCu	0.119	-0.264	0.375	-0.152
FruitsMg	-0.279	-0.673	0.021	-0.464
FruitsHg	0.310	0.536	0.391	0.298
FruitsMo	0.148	0.461	0.532	0.500
FruitsSe	-0.329	-0.387	0.188	0.357
FruitspH	-0.346	-0.740	0.018	-0.121
FruitsWC	0.011	0.720	-0.091	0.291
SoilAPAH1	-0.206	-0.651	0.639	0.050
SoilAPAH10	-0.275	-0.575	0.575	-0.343
SoilAPAH11	-0.373	-0.671	0.417	-0.289
SoilAPAH12	-0.033	0.414	0.689	0.034
SoilAPAH13	-0.514	-0.459	0.517	-0.204
SoilAPAH16	-0.632	0.064	0.388	0.156
SoilAPAH19	-0.673	0.320	0.089	0.051
SoilPAH3	0.004	-0.215	0.666	-0.218
SoilPAH4	0.183	-0.242	0.760	-0.095
SoilPAH5	0.074	-0.320	0.766	-0.035
SoilPAH7	-0.472	-0.738	0.312	0.035
SoilPAH8	-0.242	-0.287	0.623	0.291
SoilPAH9	-0.118	-0.620	0.657	-0.201
SoilPAH11	-0.558	-0.530	0.218	0.186
SoilPAH12	0.049	0.040	0.703	0.407
SoilTotalPAH	-0.300	-0.359	0.641	0.308
SoilAs	0.228	-0.719	-0.427	0.258

SoilMo	0.366	-0.401	-0.138	-0.239
SoilZn	0.655	-0.038	-0.245	0.188
SoilEC	0.615	-0.526	-0.054	-0.102
SoilOM	0.823	-0.447	0.072	-0.152
SoilOC	0.823	-0.447	0.072	-0.152
SoilPhosphorus	0.013	0.795	-0.092	0.201
SoilpH	0.177	-0.593	0.190	0.396
SoilMoisture	0.767	0.343	0.097	0.306
SoilNitrogen	0.871	-0.406	0.073	0.007
SoilAPAH2	-0.121	0.022	0.452	0.518
SoilAPAH3	0.101	-0.336	0.525	0.383
SoilAPAH4	-0.281	-0.196	0.454	0.574
SoilAPAH5	0.019	-0.388	0.467	0.334
SoilAPAH6	-0.011	-0.217	0.436	0.517
SoilAPAH7	-0.009	-0.213	0.501	0.431
SoilAPAH8	-0.644	-0.208	0.123	0.430
SoilAPAH9	0.157	-0.551	0.716	0.118
SoilAPAH14	-0.519	-0.404	0.352	-0.328
SoilAPAH15	-0.374	-0.004	0.631	-0.107
SoilAPAH17	-0.542	-0.281	0.228	-0.188
SoilAPAH18	-0.806	0.074	0.291	-0.072
SoilAPAH20	-0.128	0.718	0.142	-0.031
SoilTotal APAHs	-0.496	-0.548	0.563	-0.050
SoilPAH1	-0.245	0.214	-0.252	0.451
SoilPAH2	-0.181	0.314	-0.122	0.697
SoilPAH6	-0.477	-0.520	0.408	0.084
SoilPAH10	-0.159	0.284	0.243	0.559
SoilCd	0.789	-0.272	-0.143	0.009
SoilCr	0.662	-0.325	-0.401	0.203

SoilCo	0.656	-0.426	-0.318	0.400
SoilCu	0.720	-0.620	-0.050	0.116
SoilPb	0.747	-0.412	-0.328	0.198
SoilHg	0.397	-0.298	-0.143	-0.181
SoilNi	0.691	-0.541	-0.285	0.158
SoilSe	0.750	-0.423	-0.207	0.154
SoilCEC	0.751	-0.521	0.172	0.048
SoilGravel	0.448	-0.435	0.227	-0.240
SoilSand	-0.782	0.453	0.143	-0.124
SoilSilt	0.732	-0.404	-0.102	0.147
SoilClay	0.718	-0.608	0.007	-0.056
SoilK	0.821	-0.334	0.237	-0.029

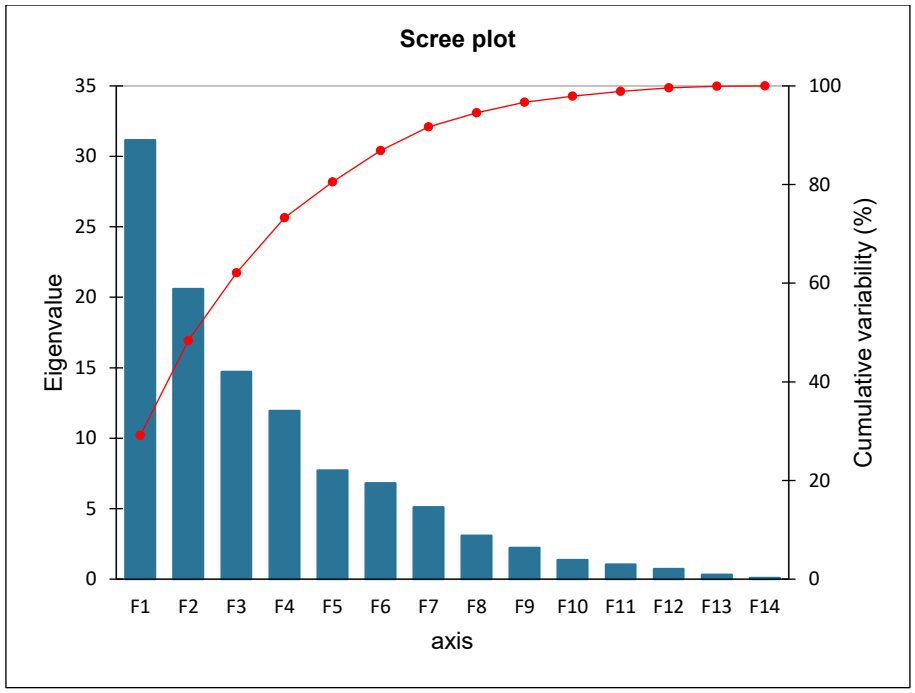

Figure 6: PCA scree plot for blueberry fruits and soil (SS3, RS2)

Table 11: PCA factor loadings for blueberry fruits and soil (SS3, RS2)

	PC1	PC2	PC3	PC4
FruitsAPAH4	0.386	0.528	0.224	-0.032
FruitsAPAH9	-0.232	0.101	0.052	-0.649
FruitsAPAH16	0.240	-0.440	0.389	0.586
FruitsAPAH20	0.019	-0.011	0.100	0.791

FruitsPAH1	0.175	0.794	-0.493	0.276
FruitsPAH2	0.175	0.822	-0.459	0.189
FruitsPAH3	0.182	0.790	-0.498	0.272
FruitsPAH4	0.177	0.781	-0.508	0.286
FruitsPAH5	0.184	0.777	-0.508	0.288
FruitsPAH6	0.172	0.792	-0.491	0.287
FruitsPAH7	0.173	0.797	-0.497	0.266
FruitsPAH8	0.168	0.800	-0.488	0.276
FruitsPAH9	0.169	0.793	-0.493	0.278
FruitsPAH10	0.184	0.771	-0.532	0.267
FruitsPAH11	0.190	0.795	-0.501	0.252
FruitsPAH12	0.205	0.792	-0.435	0.334
FruitsTotalPAHs	0.180	0.792	-0.494	0.278
FruitsAs	0.043	0.283	0.176	-0.153
FruitsB	0.216	0.637	0.513	0.089
FruitsMg	0.739	0.252	0.261	0.047
FruitsHg	0.249	-0.328	0.161	-0.188
FruitsNi	0.438	-0.058	0.162	0.191
FruitsAPAH1	0.378	0.144	0.239	0.434
FruitsAPAH2	0.633	-0.269	0.077	0.529
FruitsAPAH3	0.133	-0.455	0.632	0.326
FruitsAPAH5	0.525	-0.372	0.122	0.550
FruitsAPAH6	0.275	-0.488	0.470	0.304
FruitsAPAH7	-0.038	-0.001	-0.111	0.340
FruitsAPAH8	0.166	0.268	-0.014	0.805
FruitsAPAH10	0.439	-0.351	0.093	0.629
FruitsAPAH11	0.109	-0.669	0.560	0.070
FruitsAPAH12	0.100	0.410	0.242	0.470
FruitsAPAH13	0.389	-0.124	-0.070	0.720

FruitsAPAH14	-0.824	0.127	0.203	0.271
FruitsAPAH15	0.288	-0.163	0.253	0.553
FruitsAPAH17	0.434	-0.063	-0.123	0.612
FruitsAPAH18	-0.274	0.357	0.306	0.690
FruitsAPAH19	0.272	-0.525	0.637	0.286
FruitsTotal APAHs	0.370	-0.022	0.249	0.628
FruitsCd	0.323	0.576	0.402	0.065
FruitsCr	0.293	-0.029	0.407	0.130
FruitsCo	0.339	0.509	0.446	0.285
FruitsCu	0.366	0.264	0.342	0.129
FruitsFe	-0.111	-0.392	0.048	0.476
FruitsPb	0.273	-0.101	0.449	0.256
FruitsMo	-0.284	-0.587	-0.272	0.285
FruitsZn	0.454	0.290	0.459	0.121
FruitspH	-0.084	-0.077	-0.091	0.127
FruitsWC	-0.211	-0.614	0.098	-0.258
SoilAPAH1	0.781	0.376	0.033	0.157
SoilAPAH2	0.420	0.642	0.351	-0.110
SoilAPAH3	-0.396	0.704	0.468	-0.085
SoilAPAH4	-0.568	0.264	0.082	0.031
SoilAPAH5	-0.327	0.510	0.167	0.102
SoilAPAH6	-0.379	0.346	0.178	0.034
SoilAPAH7	-0.288	0.776	0.241	-0.204
SoilAPAH8	-0.544	0.370	0.078	-0.017
SoilAPAH9	0.751	0.482	-0.055	-0.012
SoilAPAH10	0.707	0.273	0.288	0.336
SoilAPAH11	0.815	0.180	0.342	0.189
SoilAPAH13	0.428	0.102	0.521	0.429
SoilAPAH14	0.086	0.073	0.682	0.348

SoilAPAH15	-0.214	0.141	0.754	0.351
SoilAPAH16	0.180	0.194	0.669	0.452
SoilAPAH19	-0.670	0.094	0.631	0.203
SoilAPAH20	-0.888	-0.064	0.310	0.118
SoilTotalAPAHs	0.245	0.508	0.663	0.265
SoilCEC	0.930	-0.212	-0.081	-0.237
SoilEC	0.898	-0.172	-0.261	-0.255
SoilOM	0.964	-0.156	-0.023	-0.138
SoilOC	0.964	-0.156	-0.023	-0.138
SoilGravel	0.661	-0.025	0.028	-0.273
SoilSand	-0.961	0.179	-0.013	0.083
SoilSilt	0.972	-0.094	0.071	-0.054
SoilClay	0.921	-0.268	-0.050	-0.114
SoilK	0.850	0.233	-0.285	-0.082
SoilpH	-0.831	0.152	0.169	-0.178
SoilMoisture	0.925	-0.143	-0.050	-0.250
SoilN	0.911	-0.157	-0.184	-0.028
SoilAs	0.923	-0.122	0.008	-0.255
SoilCd	0.893	-0.252	-0.020	-0.195
SoilCr	0.946	-0.131	0.138	-0.042
SoilCo	0.929	-0.188	0.090	-0.212
SoilCu	0.942	-0.248	-0.006	-0.086
SoilPb	0.905	-0.195	0.153	-0.002
SoilHg	0.620	-0.475	-0.037	0.024
SoilMo	0.909	-0.246	0.003	-0.134
SoilNi	0.941	-0.116	0.191	-0.070
SoilSe	0.929	-0.118	0.133	0.021
SoilAPAH12	-0.277	0.218	0.727	0.300
SoilAPAH17	-0.551	0.024	0.673	0.216

SoilAPAH18	-0.292	0.285	0.604	0.471
SoilPAH1	-0.509	0.363	0.509	-0.143
SoilPAH2	-0.472	0.369	0.526	-0.138
SoilPAH3	-0.212	0.515	0.575	-0.378
SoilPAH4	0.193	0.578	0.498	-0.448
SoilPAH5	0.488	0.565	0.439	-0.436
SoilPAH6	0.414	0.619	0.375	-0.464
SoilPAH7	0.526	0.567	0.359	-0.451
SoilPAH8	0.378	0.595	0.331	-0.478
SoilPAH9	0.419	0.303	-0.003	-0.242
SoilPAH10	-0.348	0.479	0.443	-0.395
SoilPAH11	0.413	0.606	0.396	-0.464
SoilPAH12	0.006	0.604	0.417	-0.483
SoilTotal PAHs	0.130	0.642	0.502	-0.478
SoilP	-0.910	-0.123	-0.030	0.347
SoilZn	0.010	0.175	0.700	-0.405

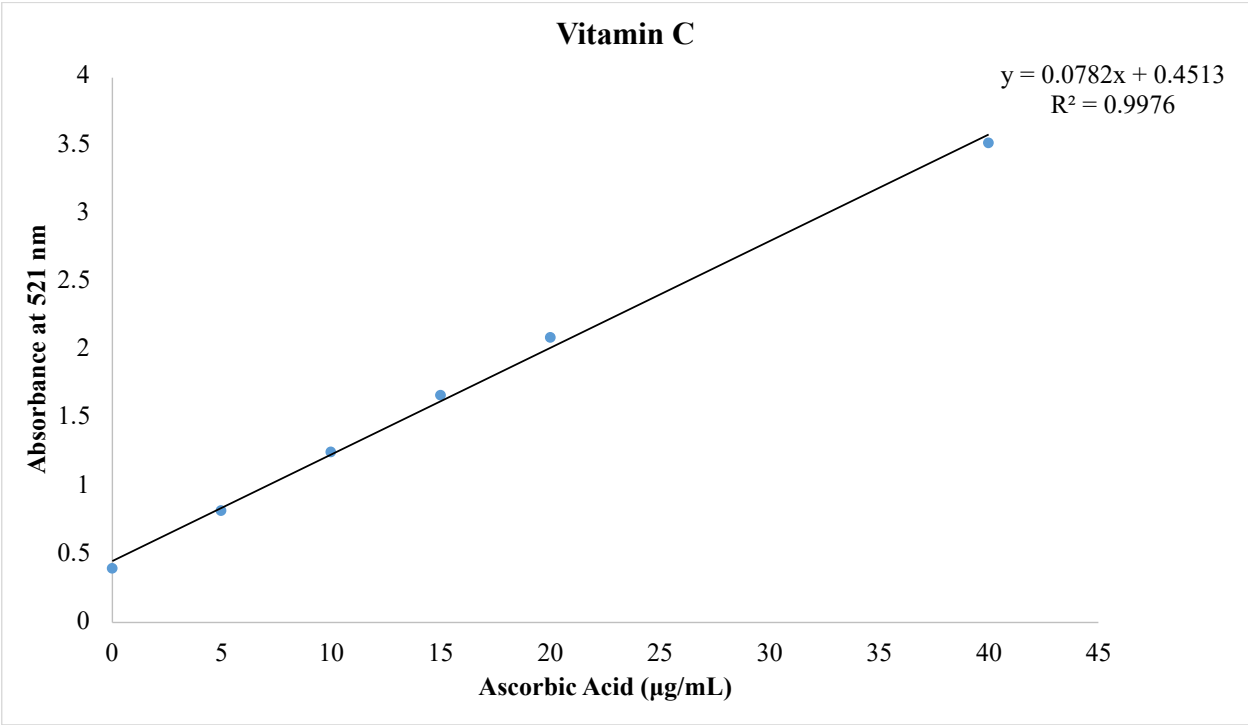

Figure 7: Shows the calibration curve for Total Vitamin C content, which was generated using standard solutions of ascorbic acid (range 0-40 µg/mL). The absorbances of these solutions were measured at 521 nm.

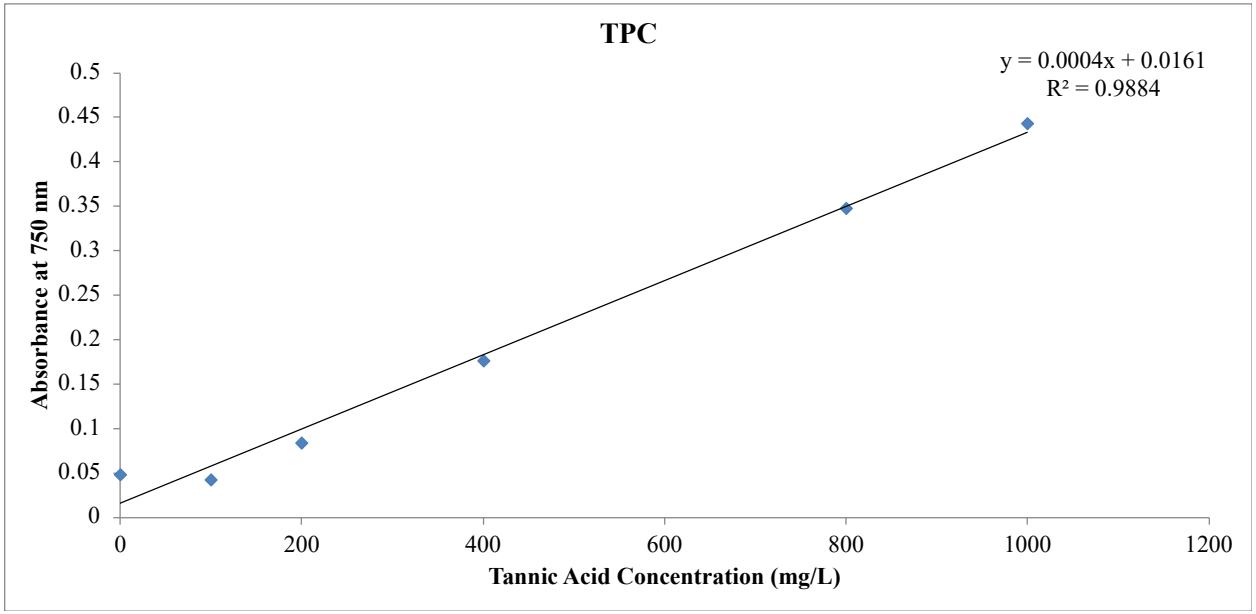

Figure 8: Shows the calibration curve for Total Phenolic content (TPC), which was generated using standard solutions of Tannic acid (100-1000 mg/L). The absorbances of these solutions were measured at 750 nm.

TAnC

Equation (1) below was used to determine the TAnC, expressed as cyanidin-3-glucoside equivalents in mg/L

Equation 1: Anthocyanins= $\frac{Ab \times MW \times DF \times 1000}{\mathrm{e} \times l}$

Abs (Absorbance) = (Abs520nm – Abs700nm)pH1.0 – (Abs520nm – Abs700nm)pH 4.5
MW = molecular weight of cyanidin-3-glucoside (449.2 g/mol)
DF = dilution factor
ε = molar extinction coefficient (26 900 L mol $^{-1}$cm^{-1})
l = optical pathlenght (1 cm)

1000 = factor to convert g to mg

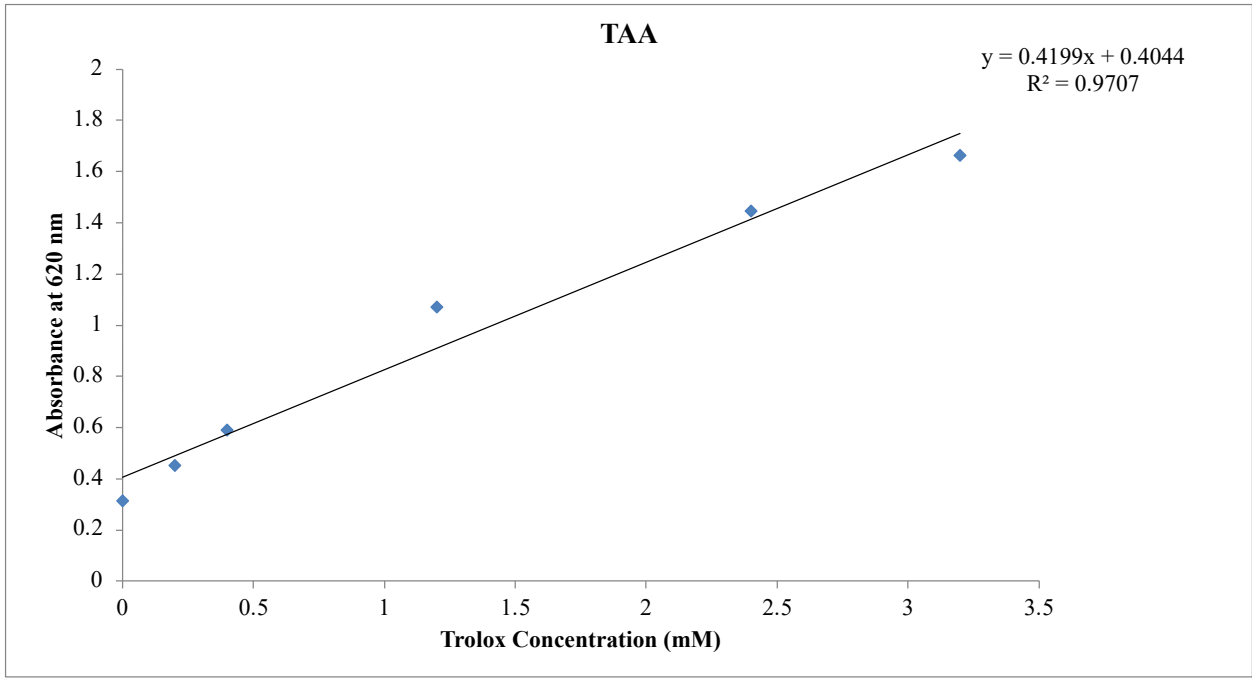

Figure 9: Shows the calibration curve for Total Antioxidant Activity (TAA), which was generated using standard solutions of Trolox (0.2-3.2 mM). The absorbances of these solutions were measured at 620 nm.

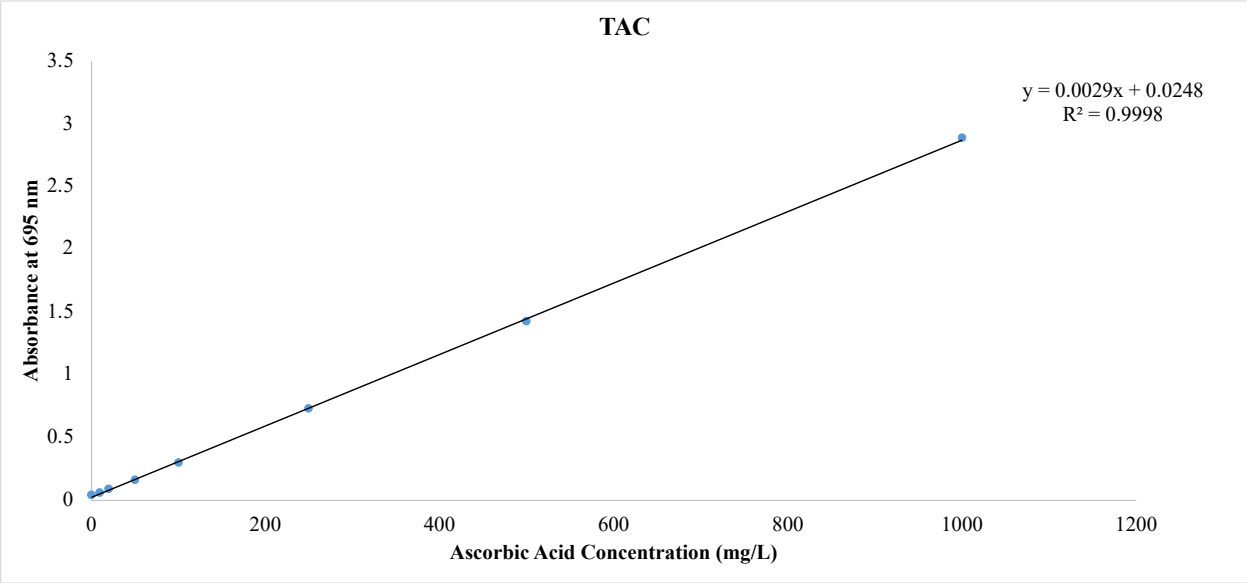

Figure 10: Shows the calibration curve for Total Antioxidant Capacity (TAC), which was generated using standard solutions of ascorbic acid (10-1000 mg/L). The absorbances of these solutions were measured at 695 nm.

Equation 2a and b:

To answer (a and b), as described by Tavakol and Wetzel. (2020), following equations can be employed:

a) How much of the variance in each variable is covered by their respective factor.

Equation: Square the factor loading of the variable to express it as a % (*i.e.,* (Factor Loading)² x 100).

b) The contribution of each variable in relation to the total variance elucidated by that factor.

Equation: Divide the squared factor loading of the variable by the eigenvalue, and express the factor as a %

Table 12: Soil guidelines for TEs, and PAHs for agricultural use (CCME SQGE and Alberta Tier 1 Soil Remediation Guidelines 2022).

Groups (Units)	Chemicals	Guidelines for agricultural use		
		SQG_E (mg/Kg)	Alberta (mg/Kg)	
			Fine	Coarse
Trace Elements (mg/kg dry)	copper (Cu)	63	63	63
	selenium (Se)	1	1.0	1.0
	zinc (Zn)	250	250	250
	arsenic (As)	17	17	17
	cadmium (Cd)	3.8	1.4	1.4
	Total chromium (Cr)	64	64	64
	cobalt (Co)	ND	20	20
	lead (Pb)	70	70	70
	Inorganic mercury (Hg)	12	6.6	6.6
	molybdenum (Mo)	ND	4.0	4.0
	nickel (Ni)	45	45	45
APAHs (ng/g)	C1 Chrysene	ND	Chrysene = 6.2	Chrysene = 6.2
	C2 Chrysene	ND		
	C3 Chrysene	ND		
	C4 Chrysene	ND		
	C1 Dibenzothiophene	ND	ND	ND

	C2 Dibenzothiophene	ND	ND	ND
	C3 Dibenzothiophene	ND	ND	ND
	C4 Dibenzothiophene	ND	ND	ND
	Dibenzothiophene	ND	ND	ND
	C1 Fluorene	ND	Fluorene = 0.40	Fluorene = 0.34
	C2 Fluorene	ND		
	C3 Fluorene	ND		
	C4 Fluorene	ND		
	C2 Naphthalene	ND	Naphthalene = 0.014	Naphthalene = 0.017
	C3 Naphthalene	ND		
	C4 Naphthalene (Butyl)	ND		
	C2 Phenanthrene	ND	Phenanthrene = 0.11	Phenanthrene = 0.061
	C3 Phenanthrene	ND		
	C4 Phenanthrene	ND		

	Total APAHs	ND	ND	ND
PAHs (ng/g)	Acenapthene	ND	0.33	0.38
	Acenapthylene	ND	ND	ND
	Anthracene	2.5	1.3	0.0056
	Benz[a]anthracene	ND	6.2	6.2
	Benzo[a]pyrene	20	0.60	0.60
	Benzo[b]fluoranthene	ND	6.2	6.2
	Benzo[g,h,i]perylene	ND	ND	ND
	Benzo[k]fluoranthene	ND	6.2	6.2
	Dibenzo[a,h]anthracene	ND	ND	ND
	Fluoranthene	50	15.4	0.055
	Indeno[1,2,3-c,d]pyrene	ND	ND	ND
	Pyrene	ND	7.7	0.15
	Total PAHs	ND	ND	ND

ND = Not determined or Not Available.

Table 13: maximum allowed limits (MAL) for chemicals (TEs and PAHs) in food guidelines based on WHO/FAO and European Commission (EU).

Groups (Units)	Chemicals	MAL for Chemicals in Food	
		WHO/FAO	EU Commission
Trace Elements (ppm)	boron (B)	ND	ND
	copper (Cu)	0.10 mg/kg (Edible vegetable oils)	ND
	iron (Fe)	2.50 mg/kg (Edible vegetable oils)	ND
	magnesium (Mg)	ND	ND
	selenium (Se)	ND	ND
	zinc (Zn)	ND	ND
	arsenic (As)	0.10 mg/kg (Edible Vegetable oils)	0.02 mg/kg wet weight (Fruit Juices)
	cadmium (Cd)	0.05 mg/kg (Fruiting vegetables, cucurbits and other than cucurbits)	0.03 mg/kg wet weight (Berries and small fruits)
	chromium (Cr)	ND	ND
	cobalt (Co)	ND	ND

	lead (Pb)	0.20 mg/kg (Berries and other small fruits)	0.05 mg/kg wet weight (Berries and other small fruits)
	mercury (Hg)	NE	0.01 mg/kg (Berries and small fruits)
	molybdenum (Mo)	ND	ND
	nickel (Ni)	ND	ND
APAHs (ng/g)	C1 Chrysene	ND	10.00 µg/kg for the sum of benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene and chrysene for oil and fats
	C2 Chrysene	ND	
	C2 Naphthalene	ND	ND
	C2 Phenanthrene	ND	ND
	C3 Chrysene	ND	ND
	C3 Naphthalene	ND	ND
	C3 Phenanthrene	ND	ND
	C4 Chrysene	ND	ND
	C4 Naphthalene (Butyl)	ND	ND
	C4 Phenanthrene	ND	ND
	C1 Dibenzothiophene	ND	ND
	C1 Fluorene	ND	ND
	C2 Dibenzothiophene	ND	ND
	C2 Fluorene	ND	ND

	C3 Dibenzothiophene	ND	ND
	C3 Fluorene	ND	ND
	C4 Dibenzothiophene	ND	ND
	C4 Fluorene	ND	ND
	Dibenzothiophene	ND	ND
	Total APAHs	ND	ND
PAHs	Acenapthene	ND	ND
	Acenapthylene	ND	ND
	Anthracene	ND	ND
	Benz[a]anthracene	ND	2.00 µg/kg for benzo(a)pyrene for oil and fats & 10.00 µg/kg for the sum of benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene and chrysene for oil and fats
	Benzo[a]pyrene	ND	
	Benzo[b]fluoranthene	ND	
	Benzo[g,h,i]perylene	ND	ND
	Benzo[k]fluoranthene	ND	ND
	Dibenzo[a,h]anthracene	ND	ND

	Fluoranthene	ND	ND
	Indeno[1,2,3-c,d]pyrene	ND	ND
	Pyrene	ND	ND
	Total PAHs	ND	ND

ND = Not determined or Not Available.

Table 14: Method Detection Limits (MDL) for PAHs in Berries and Sediments

Analyte	**Limit of Detection (ng/g)**
1,7-Dimethylphenanthrene	0.011
1,8-Dimethylphenanthrene	0.014
1-Methylnaphthalene	0.011
1-Methylphenanthrene	0.006
2,6-Dimethylphenanthrene	0.011
2-Methylnaphthalene	0.011
2-Methylphenanthrene	0.007
3,6-Dimethylphenanthrene	0.015
3-Methylphenanthrene	0.007
9/4-Methylphenanthrene	0.006
C1 Chrysene	0.008
C2 Chrysene	0.002

C2 Naphthalene	0.010
C2 Phenanthrene	0.013
C3 Chrysene	0.002
C3 Naphthalene	0.009
C3 Phenanthrene	0.020
C4 Chrysene	0.002
C4 Naphthalene (Butyl)	0.008
C4 Phenanthrene	0.028
Retene	No data

Table 15: Method Detection Limits (MDL) for PAHs in Berries and Sediments

Analyte	**Limit of Detection (ng/g)**
C1 Benzo[a]pyrene	0.007
C1 Dibenzothiophene	0.003
C1 Fluorene	0.010
C1 Pyrene	0.006
C2 Benzo[a]pyrene	0.007
C2 Dibenzothiophene	0.010
C2 Fluorene	0.010
C2 Pyrene	0.035

C3 Dibenzothiophene	0.005
C3 Fluorene	0.010
C3 Pyrene	0.035
C4 Dibenzothiophene	0.005
C4 Fluorene	No data
C4 Pyrene	0.035
Dibenzothiophene	0.056

Table 16: Method Detection Limits (MDL) for PAHs in Berries

Analyte	**Limit of Detection (ng/g)**
Acenapthene	0.135
Acenapthylene	0.113
Anthracene	0.087
Benz[a]anthracene	0.118
Benzo[a]pyrene	0.110
Benzo[b]fluoranthene	0.059
Benzo[g,h,i]perylene	0.065
Benzo[k]fluoranthene	0.088
Chrysene	0.158

Dibenzo[a,h]anthracene	0.092
Fluoranthene	0.105
Fluorene	0.070
Indeno[1,2,3-c,d]pyrene	0.227
Naphthalene	0.055
Phenanthrene	0.152
Pyrene	0.091

Table 17: Method Detection Limits (MDL) for PAHs in Sediments

Analyte	**Limit of Detection (ng/g)**
Acenapthene	3.369
Acenapthylene	2.820
Anthracene	2.170
Benz[a]anthracene	2.951
Benzo[a]pyrene	2.745
Benzo[b]fluoranthene	1.478
Benzo[g,h,i]perylene	1.634
Benzo[k]fluoranthene	2.194
Chrysene	3.952
Dibenzo[a,h]anthracene	2.292

Fluoranthene	2.625
Fluorene	1.739
Indeno[1,2,3-c,d]pyrene	5.666
Naphthalene	1.387
Phenanthrene	3.802
Pyrene	2.269

Table 18: Method Detection Limits (MDL) for Trace Elements in Berries and Sediments

Trace Elements	**Method Detection Limit (ppm)**
Aluminum	0.017
Antimony	0.0003
Arsenic	0.001
Beryllium	0.0001
Boron	0.01
Cadmium	0.001
Chromium	0.012
Cobalt	0.0003
Copper	0.006
Iron	0.05
Lead	0.002

Magnesium	0.04
Manganese	0.002
Mercury	0.0001
Molybdenum	0.001
Nickel	0.01
Selenium	0.005
Tin	0.02
Titanium	0.02
Zinc	0.05

Table 19: % Recovery for PAHs in Berry samples

Berry Sample ID	d-PAH IPIS Corrected Recovery (%)																	
	Acenaphthene (d)	Acenaphthylene (d)	Anthracene (d)	Benz[a]anthracene (d)	Benzo[a]pyrene (d)	Benzo[b]fluoranthene (d)	Benzo[g,h,i]perylene (d)	Benzo[k]fluoranthene (d)	Chrysene (d)	Dibenz[a,h]anthracene (d)	Fluoranthene (d)	Fluorene (d)	Indeno[1,2,3-c,d]pyrene (d	Naphthalene (d)	Phenanthrene (d)	Pyrene (d)
Blank	81.20	56.50	100.00	122.80	63.50	112.90	96.70	107.80	120.80	92.50	127.30	105.50	87.80	62.90	94.20	119.10
Reference-1	95.20	79.80	100.00	172.60	83.30	103.10	88.30	88.20	161.70	83.70	183.50	84.90	82.00	71.80	98.40	185.00
Reference-spike-1	68.20	54.90	100.00	117.30	95.90	112.70	105.40	111.20	108.00	107.10	114.30	75.30	102.70	55.00	100.00	113.40
A1	65.80	60.80	100.00	116.00	94.10	102.20	85.80	99.60	104.80	79.70	118.50	89.60	81.60	49.20	99.70	118.50
A5	57.80	49.30	100.00	97.40	74.40	91.40	112.50	89.90	89.30	111.90	93.80	61.30	107.20	50.30	98.20	94.30
A7	73.00	66.70	100.00	122.00	88.80	113.20	104.00	100.90	112.60	103.10	123.10	79.20	96.20	59.10	94.10	121.90
K1	78.30	56.80	100.00	123.00	92.80	108.90	99.10	105.70	111.40	91.10	144.40	86.70	94.90	52.50	100.90	146.60
K5	77.00	53.90	100.00	129.10	106.30	123.30	126.40	123.60	116.80	130.00	143.70	82.40	119.80	62.20	94.20	170.50
K6	70.80	34.90	100.00	80.90	33.20	68.50	50.00	61.20	81.90	30.30	161.00	72.10	47.00	47.90	89.60	172.30
N1	85.90	32.50	100.00	129.30	97.80	119.10	99.30	107.60	119.90	90.20	132.10	90.60	93.30	69.10	105.60	133.10
N3 bare hands + duct	72.10	60.80	100.00	128.40	100.80	115.70	102.10	111.40	112.30	97.30	166.50	80.30	96.90	57.60	96.30	178.90
N3 bare hands	65.20	54.70	100.00	111.20	88.20	100.10	89.60	98.00	101.00	88.00	153.40	69.70	84.90	53.80	106.30	107.60
N3 gloves	72.10	58.70	100.00	123.60	119.60	110.20	99.90	95.40	109.10	98.00	123.30	81.00	93.00	53.00	97.50	122.20
N4 gloves	78.90	51.30	100.00	133.80	104.60	121.90	114.30	115.90	121.40	112.80	199.00	85.70	104.90	60.00	101.30	197.90
S1	52.50	41.70	100.00	90.70	67.50	79.70	102.70	79.10	83.20	79.60	91.90	57.70	72.40	42.10	84.00	91.60
S5	67.50	47.70	100.00	124.60	145.80	163.90	104.70	149.70	114.10	105.50	121.60	72.40	96.50	53.30	89.70	121.10
S10	74.80	53.80	100.00	120.90	93.50	111.10	98.90	112.30	113.10	96.50	121.40	79.60	92.80	60.80	93.10	122.00
K6	95.60	42.20	100.00	140.00	109.10	132.30	135.60	129.80	125.30	140.90	140.30	128.90	132.50	70.20	110.40	141.20
Blank-1	56.63	43.31	100.00	100.10	72.81	94.64	96.10	95.39	100.63	93.97	95.27	67.18	89.76	41.94	82.17	92.37
A8	36.73	31.57	100.00	89.23	73.37	87.88	82.24	96.72	86.81	98.55	106.16	44.09	86.44	24.85	78.89	105.36
A9	59.82	49.78	100.00	132.73	100.71	127.95	116.67	138.45	129.67	141.94	92.39	69.84	113.70	45.46	79.88	93.62
A10	43.06	36.17	100.00	215.38	181.70	213.24	185.91	213.29	205.78	216.89	152.40	55.33	197.97	25.87	72.47	153.91
K2	62.96	44.53	100.00	124.11	102.43	121.79	108.89	128.38	121.91	132.41	91.34	70.32	114.24	45.04	78.88	90.83
N4 bare hands +duct	51.68	34.65	100.00	123.57	96.42	146.48	97.62	127.69	122.62	118.85	93.14	64.80	99.80	32.10	80.48	92.20
S3	45.62	37.08	100.00	128.56	91.24	117.11	77.73	126.18	122.21	91.70	90.54	59.24	81.41	31.27	75.15	90.60
N2 Gloves	55.14	21.21	100.00	134.32	105.74	127.57	83.68	136.09	127.60	105.16	92.60	64.37	91.04	92.60	39.06	93.47
N2 Bare hands	55.88	19.22	100.00	108.06	38.01	87.83	43.48	94.01	109.06	58.17	97.97	77.97	60.32	36.41	90.84	96.29
N4 gloves	52.21	41.03	100.00	218.62	117.07	196.25	112.50	211.85	222.25	135.98	171.63	61.66	124.73	36.20	80.22	172.88
N4 Bare hands	64.34	44.54	100.00	69.59	38.25	70.85	38.59	78.14	70.68	45.70	104.30	75.60	41.79	43.06	90.39	101.72
Blank-2	42.95	35.46	100.00	118.01	64.77	107.77	56.21	112.37	123.00	70.87	94.31	58.72	67.77	28.96	74.06	91.20
A4	41.61	36.22	100.00	103.51	59.73	103.58	105.33	107.16	101.74	123.83	87.93	54.99	111.96	25.47	73.37	87.03
A2	48.69	41.79	100.00	103.93	43.97	92.43	56.77	99.85	108.58	76.02	137.05	62.63	67.01	29.76	79.28	114.07
A3	29.78	24.92	100.00	68.08	24.10	63.17	37.68	58.62	72.64	49.53	57.78	37.90	44.52	18.89	78.00	57.77
A4	51.39	42.76	100.00	113.25	93.56	178.49	58.75	203.06	115.62	78.35	93.87	88.18	65.80	31.22	80.38	94.07
A6	46.01	38.33	100.00	102.89	58.64	79.99	45.26	90.15	101.89	49.66	93.23	59.91	47.13	21.66	78.75	94.16
K3	60.49	46.31	100.00	98.56	42.22	81.49	65.98	69.30	101.02	89.48	92.58	73.12	88.42	35.87	85.10	91.26
K4	40.20	36.17	100.00	120.55	169.22	115.45	95.62	119.01	117.88	106.56	94.00	54.65	95.94	20.20	77.13	95.10
N2 bare hands + duct	65.32	37.29	100.00	108.06	38.01	87.83	43.48	94.01	109.06	58.17	97.97	60.32	36.41	90.84	96.29	
N4 gloves	52.21	41.03	100.00	218.62	117.07	196.25	112.50	211.85	222.25	135.98	171.63	61.66	124.73	36.20	80.22	172.88
N4 bare hands	64.34	44.54	100.00	69.59	38.25	70.85	38.59	78.14	70.68	45.70	104.30	75.60	41.79	43.06	90.39	101.72
S3	50.08	50.33	100.00	170.18	48.59	102.36	61.94	101.03	155.06	70.78	95.66	61.99	65.48	29.26	81.83	95.13
S4	56.15	48.37	100.00	113.83	94.44	157.06	67.25	165.94	116.91	76.58	96.53	66.44	69.65	37.55	83.00	97.96
S6	48.47	38.87	100.00	108.01	59.96	98.79	77.34	100.48	109.91	89.21	91.96	60.06	79.57	35.13	78.48	91.37
S7	56.48	49.29	100.00	126.61	63.14	109.76	67.34	112.29	124.93	77.90	101.40	68.21	69.45	34.12	85.94	103.83
S8	31.19	25.12	100.00	71.81	40.89	66.95	49.90	68.76	74.57	56.61	85.28	39.71	49.31	19.61	86.80	59.64
S9	46.26	36.38	100.00	106.71	72.70	95.58	88.26	105.93	104.59	102.72	86.60	56.85	89.81	32.93	74.41	87.78
Blank	56.63	43.31	100.00	100.10	72.81	94.64	96.10	95.39	100.63	93.97	95.27	67.18	89.76	41.94	82.17	92.37
Reference-1	59.85	47.74	100.00	212.46	145.26	186.64	76.45	190.83	216.11	77.90	98.58	68.65	76.26	40.08	87.15	98.21
Reference-spike-1	58.42	47.85	100.00	131.15	114.29	128.08	132.72	132.57	125.88	150.65	91.57	66.28	133.65	40.68	77.56	93.24
A8	36.73	31.57	100.00	89.23	73.37	87.88	82.24	96.72	86.81	98.55	106.16	44.09	86.44	24.85	78.89	105.36
A9	59.82	49.78	100.00	132.73	100.71	127.95	116.67	138.45	129.67	141.94	92.39	69.84	113.70	45.46	79.88	93.62
A10	43.06	36.17	100.00	215.38	181.70	213.24	185.91	213.29	205.78	216.89	152.40	55.33	197.97	25.87	72.47	153.91
K2	62.96	44.53	100.00	124.11	102.43	121.79	108.89	128.38	121.91	132.41	91.34	70.32	114.24	45.04	78.88	90.83
N4 bare hands + duct	51.68	34.65	100.00	123.57	96.42	146.48	97.62	127.69	122.62	118.85	93.14	64.80	99.80	32.10	80.48	92.20
S3	45.62	37.08	100.00	128.56	91.24	117.11	77.73	126.18	122.21	91.70	90.54	59.24	81.41	31.27	75.15	90.60
Reference-2	60.30	51.50	100.00	109.93	70.81	108.03	83.76	110.05	114.54	105.49	98.70	73.30	94.87	38.63	90.03	99.62
Reference-spike-2	39.30	32.68	100.00	81.90	51.94	81.19	74.90	88.01	85.14	66.93	45.80	130.94	23.73	78.31	65.61	
A2	41.61	36.22	100.00	103.51	59.73	103.58	105.33	107.16	101.74	123.83	87.93	54.99	111.96	25.47	73.37	87.03
A7	48.69	41.79	100.00	103.93	43.97	92.43	56.77	99.85	108.58	76.02	137.05	62.63	67.01	29.76	79.28	114.07
A3	29.78	24.92	100.00	68.08	24.10	63.17	37.68	58.62	72.64	49.53	57.78	37.90	44.52	18.89	78.00	57.77
A4	51.39	42.76	100.00	113.25	93.56	178.49	58.75	203.06	115.62	78.35	93.87	88.18	65.80	31.22	80.38	94.07
A6	46.01	38.33	100.00	102.89	58.64	79.99	45.26	90.15	101.89	49.66	93.23	59.91	47.13	21.66	78.75	94.16
K3	60.49	46.31	100.00	98.56	42.22	81.49	65.98	69.30	101.02	89.48	92.58	73.12	88.42	35.87	85.10	91.26
K4	40.20	36.17	100.00	120.55	169.22	115.45	95.62	119.01	117.88	106.56	94.00	54.65	95.94	20.20	77.13	95.10
N2 bare hands + duct	65.32	37.29	100.00	108.06	38.01	87.83	43.48	94.01	109.06	58.17	97.97	60.32	36.41	90.84	96.29	
N4 gloves	52.21	41.03	100.00	218.62	117.07	196.25	112.50	211.85	222.25	135.98	171.63	61.66	124.73	36.20	80.22	172.88
N4 bare hands	64.34	44.54	100.00	69.59	38.25	70.85	38.59	78.14	70.68	45.70	104.30	75.60	41.79	43.06	90.39	101.72
S3	50.08	50.33	100.00	170.18	48.59	102.36	61.94	101.03	155.06	70.78	95.66	61.99	65.48	29.26	81.83	95.13
S4	56.15	48.37	100.00	113.83	94.44	157.06	67.25	165.94	116.91	76.58	96.53	66.44	69.65	37.55	83.00	97.96
S6	48.47	38.87	100.00	108.01	59.96	98.79	77.34	100.48	109.91	89.21	91.96	60.06	79.57	35.13	78.48	91.37
S7	56.48	49.29	100.00	126.61	63.14	109.76	67.34	112.29	124.93	77.90	101.40	68.21	69.45	34.12	85.94	103.83
S8	31.19	25.12	100.00	71.81	40.89	66.95	49.90	68.76	74.57	56.61	85.28	39.71	49.31	19.61	86.80	59.64
S9	46.26	36.38	100.00	106.71	72.70	95.58	88.26	105.93	104.59	102.72	86.60	56.85	89.81	32.93	74.41	87.78
Blank	56.63	43.31	100.00	100.10	72.81	94.64	96.10	95.39	100.63	93.97	95.27	67.18	89.76	41.94	82.17	92.37
Reference-1	59.85	47.74	100.00	212.46	145.26	186.64	76.45	190.83	216.11	77.90	98.58	68.65	76.26	40.08	87.15	98.21
Reference-spike-1	58.42	47.85	100.00	131.15	114.29	128.08	132.72	132.57	125.88	150.65	91.57	66.28	133.65	40.68	77.56	93.24
A8	36.73	31.57	100.00	89.23	73.37	87.88	82.24	96.72	86.81	98.55	106.16	44.09	86.44	24.85	78.89	105.36
A9	59.82	49.78	100.00	132.73	100.71	127.95	116.67	138.45	129.67	141.94	92.39	69.84	113.70	45.46	79.88	93.62
A10	43.06	36.17	100.00	215.38	181.70	213.24	185.91	213.29	205.78	216.89	152.40	55.33	197.97	25.87	72.47	153.91
K2	62.96	44.53	100.00	124.11	102.43	121.79	108.89	128.38	121.91	132.41	91.34	70.32	114.24	45.04	78.88	90.83
N4 bare hands + duct	51.68	34.65	100.00	123.57	96.42	146.48	97.62	127.69	122.62	118.85	93.14	64.80	99.80	32.10	80.48	92.20
S3	45.62	37.08	100.00	128.56	91.24	117.11	77.73	126.18	122.21	91.70	90.54	59.24	81.41	31.27	75.15	90.60
N2 gloves	55.14	21.21	100.00	134.32	105.74	127.57	83.68	136.09	127.60	105.16	92.60	64.37	91.04	92.60	39.06	93.47
N2 Gloves	55.14	21.21	100.00	134.32	105.74	127.57	83.68	136.09	127.60	105.16	92.60	64.37	91.04	92.60	39.06	93.47
N2 Bare hands	55.88	19.22	100.00	108.06	38.01	87.83	43.48	94.01	109.06	58.17	97.97	77.97	60.32	36.41	90.84	96.29
N4 gloves	52.21	41.03	100.00	218.62	117.07	196.25	112.50	211.85	222.25	135.98	171.63	61.66	124.73	36.20	80.22	172.88
N4 Bare hands	64.34	44.54	100.00	69.59	38.25	70.85	38.59	78.14	70.68	45.70	104.30	75.60	41.79	43.06	90.39	101.72
Blank-2	42.95	35.46	100.00	118.01	64.77	107.77	56.21	112.37	123.00	70.87	94.31	58.72	67.77	28.96	74.06	91.20
A4	41.61	36.22	100.00	103.51	59.73	103.58	105.33	107.16	101.74	123.83	87.93	54.99	111.96	25.47	73.37	87.03
A2	48.69	41.79	100.00	103.93	43.97	92.43	56.77	99.85	108.58	76.02	137.05	62.63	67.01	29.76	79.28	114.07
A3	29.78	24.92	100.00	68.08	24.10	63.17	37.68	58.62	72.64	49.53	57.78	37.90	44.52	18.89	78.00	57.77
A4	51.39	42.76	100.00	113.25	93.56	178.49	58.75	203.06	115.62	78.35	93.87	88.18	65.80	31.22	80.38	94.07
A6	46.01	38.33	100.00	102.89	58.64	79.99	45.26	90.15	101.89	49.66	93.23	59.91	47.13	21.66	78.75	94.16
K3	60.49	46.31	100.00	98.56	42.22	81.49	65.98	69.30	101.02	89.48	92.58	73.12	88.42	35.87	85.10	91.26
K4	40.20	36.17	100.00	120.55	169.22	115.45	95.62	119.01	117.88	106.56	94.00	54.65	95.94	20.20	77.13	95.10
N2 bare hands + duct	65.32	37.29	100.00	108.06	38.01	87.83	43.48	94.01	109.06	58.17	97.97	60.32	36.41	90.84	96.29	
N4 gloves	52.21	41.03	100.00	218.62	117.07	196.25	112.50	211.85	222.25	135.98	171.63	61.66	124.73	36.20	80.22	172.88
N4 bare hands	64.34	44.54	100.00	69.59	38.25	70.85	38.59	78.14	70.68	45.70	104.30	75.60	41.79	43.06	90.39	101.72
S3	50.08	50.33	100.00	170.18	48.59	102.36	61.94	101.03	155.06	70.78	95.66	61.99	65.48	29.26	81.83	95.13
S4	56.15	48.37	100.00	113.83	94.44	157.06	67.25	165.94	116.91	76.58	96.53	66.44	69.65	37.55	83.00	97.96
S6	48.47	38.87	100.00	108.01	59.96	98.79	77.34	100.48	109.91	89.21	91.96	60.06	79.57	35.13	78.48	91.37
S7	56.48	49.29	100.00	126.61	63.14	109.76	67.34	112.29	124.93	77.90	101.40	68.21	69.45	34.12	85.94	103.83
S8	31.19	25.12	100.00	71.81	40.89	66.95	49.90	68.76	74.57	56.61	85.28	39.71	49.31	19.61	86.80	59.64
S9	46.26	36.38	100.00	106.71	72.70	95.58	88.26	105.93	104.59	102.72	86.60	56.85	89.81	32.93	74.41	87.78
Blank	56.63	43.31	100.00	100.10	72.81	94.64	96.10	95.39	100.63	93.97	95.27	67.18	89.76	41.94	82.17	92.37
Reference-1	59.85	47.74	100.00	212.46	145.26	186.64	76.45	190.83	216.11	77.90	98.58	68.65	76.26	40.08	87.15	98.21
Reference-spike-1	58.42	47.85	100.00	131.15	114.29	128.08	132.72	132.57	125.88	150.65	91.57	66.28	133.65	40.68	77.56	93.24
A8	36.73	31.57	100.00	89.23	73.37	87.88	82.24	96.72	86.81	98.55	106.16	44.09	86.44	24.85	78.89	105.36
A9	59.82	49.78	100.00	132.73	100.71	127.95	116.67	138.45	129.67	141.94	92.39	69.84	113.70	45.46	79.88	93.62
A10	43.06	36.17	100.00	215.38	181.70	213.24	185.91	213.29	205.78	216.89	152.40	55.33	197.97	25.87	72.47	153.91
K2	62.96	44.53	100.00	124.11	102.43	121.79	108.89	128.38	121.91	132.41	91.34	70.32	114.24	45.04	78.88	90.83
N4 bare hands + duct	51.68	34.65	100.00	123.57	96.42	146.48	97.62	127.69	122.62	118.85	93.14	64.80	99.80	32.10	80.48	92.20
S3	45.62	37.08	100.00	128.56	91.24	117.11	77.73	126.18	122.21	91.70	90.54	59.24	81.41	31.27	75.15	90.60
N2 gloves	55.14	21.21	100.00	134.32	105.74	127.57	83.68	136.09	127.60	105.16	92.60	64.37	91.04	92.60	39.06	93.47
N2 bare hands	55.88	19.22	100.00	108.06	38.01	87.83	43.48	94.01	109.06	58.17	97.97	77.97	60.32	36.41	90.84	96.29
N4 gloves	52.21	41.03	100.00	218.62	117.07	196.25	112.50	211.85	222.25	135.98	171.63	61.66	124.73	36.20	80.22	172.88
N4 bare hands	64.34	44.54	100.00	69.59	38.25	70.85	38.59	78.14	70.68	45.70	104.30	75.60	41.79	43.06	90.39	101.72
S3	50.08	50.33	100.00	170.18	48.59	102.36	61.94	101.03	155.06	70.78	95.66	61.99	65.48	29.26	81.83	95.13
S4	56.15	48.37	100.00	113.83	94.44	157.06	67.25	165.94	116.91	76.58	96.53	66.44	69.65	37.55	83.00	97.96
S6	48.47	38.87	100.00	108.01	59.96	98.79	77.34	100.48	109.91	89.21	91.96	60.06	79.57	35.13	78.48	91.37
S7	56.48	49.29	100.00	126.61	63.14	109.76	67.34	112.29	124.93	77.90	101.40	68.21	69.45	34.12	85.94	103.83
S8	31.19	25.12	100.00	71.81	40.89	66.95	49.90	68.76	74.57	56.61	85.28	39.71	49.31	19.61	86.80	59.64
S9	46.26	36.38	100.00	106.71	72.70	95.58	88.26	105.93	104.59	102.72	86.60	56.85	89.81	32.93	74.41	87.78
Blank	56.63	43.31	100.00	100.10	72.81	94.64	96.10	95.39	100.63	93.97	95.27	67.18	89.76	41.94	82.17	92.37
N3 Bare hands	65.22	54.74	100.00	111.17	88.19	100.10	89.61	98.00	100.99	88.03	153.40	69.70	84.86	53.76	106.27	107.60
N3 Gloves	72.09	58.71	100.00	123.59	119.58	110.19	99.95	95.39	109.09	97.95	123.31	81.01	92.96	53.01	97.47	122.23
N4 Gloves	78.94	51.27	100.00	133.75	104.56	121.89	114.30	115.89	121.43	112.82	198.99	85.68	104.92	60.00	101.34	197.92
S1	52.48	41.74	100.00	90.69	67.49	79.66	102.74	79.14	83.17	79.57	91.86	57.65	72.40	42.14	84.03	91.62
S5	67.54	47.68	100.00	124.56	145.81	163.93	104.67	149.66	114.06	105.46	121.64	72.38	96.51	53.34	89.68	121.11
S10	74.78	53.76	100.00	120.95	93.51	111.15	98.85	112.29	113.15	96.45	121.40	79.61	92.80	60.83	93.11	122.01
K6	95.60	42.19	100.00	139.97	109.11	132.29	135.58	129.77	125.33	140.90	140.28	128.87	132.53	70.23	110.36	141.21
Blank	81.18	56.49	100.00	122.78	63.49	112.91	96.70	107.82	120.84	92.45	127.28	105.49	87.80	62.92	94.23	119.11
A1	65.79	60.80	100.00	115.95	94.13	102.23	85.81	99.57	104.84	79.70	118.53	89.55	81.61	49.22	99.75	118.55
A5	57.79	49.30	100.00	97.37	74.36	91.36	112.45	89.89	89.27	111.91	93.75	61.27	107.17	50.29	98.15	94.26
A7	72.95	66.70	100.00	121.99	88.77	113.19	103.97	100.91	112.63	103.14	123.11	79.19	96.19	59.10	94.05	121.89
K1	78.29	56.79	100.00	122.97	92.83	108.88	99.07	105.68	111.41	91.07	144.44	86.70	94.92	52.53	100.92	146.57
K5	76.98	53.89	100.00	129.14	106.31	123.30	126.43	123.58	116.84	130.03	143.72	82.45	119.77	62.21	94.22	170.54
K6	70.84	34.87	100.00	80.93	33.18	68.34	49.99	61.23	81.90	30.31	160.98	72.12	47.01	47.93	88.96	172.28
N1	85.88	32.51	100.00	129.33	97.79	119.05	99.29	107.63	119.88	90.20	132.06	90.65	93.34	69.13	105.59	133.09
N3 bare hands + duct	72.14	60.77	100.00	128.36	100.78	115.66	102.09	111.42	112.26	97.33	166.53	80.27	96.91	57.64	96.30	178.89
N3 gloves	72.09	58.71	100.00	123.59	119.58	110.19	99.95	95.39	109.09	97.95	123.31	81.01	92.96	53.01	97.47	122.23
N4 gloves	78.94	51.27	100.00	133.75	104.56	121.89	114.30	115.89	121.43	112.82	198.99	85.68	104.92	60.00	101.34	197.92
S1	52.48	41.74	100.00	90.69	67.49	79.66	102.74	79.14	83.17	79.57	91.86	57.65	72.40	42.14	84.03	91.62
S5	67.54	47.68	100.00	124.56	145.81	163.93	104.67	149.66	114.06	105.46	121.64	72.38	96.51	53.34	89.68	121.11
S10	74.78	53.76	100.00	120.95	93.51	111.15	98.85	112.29	113.15	96.45	121.40	79.61	92.80	60.83	93.11	122.01
K6	95.60	42.19	100.00	139.97	109.11	132.29	135.58	129.77	125.33	140.90	140.28	128.87	132.53	70.23	110.36	141.21

Table 20: % Recovery for PAHs in Sediment samples

Sediment Sample IDs	d-PAH IPIS Corrected Recovery (%)															
	Acenapthene (d)	Acenapthylene (d)	Anthracene (d)	Benz[a]anthracene (d)	Benzo[a]pyrene (d)	Benzo[b]fluoranthene (d)	Benzo[g,h,i]perylene (d)	Benzo[k]fluoranthene (d)	Chrysene (d)	Dibenzo[a,h]anthracene (d)	Fluoranthene (d)	Fluorene (d)	Indeno[1,2,3-c,d]pyrene (d)	Naphthalene (d)	Phenanthrene (d)	Pyrene (d)
BLANK-2	93.63	81.94	100.00	122.47	86.16	110.33	96.37	100.17	106.43	94.56	187.42	101.00	94.48	94.64	105.58	172.75
Reference-2	71.80	73.90	100.00	117.50	129.60	118.10	158.10	119.10	97.60	193.10	102.50	84.00	173.30	68.20	113.30	101.20
N3	95.00	54.10	100.00	136.20	109.20	144.70	151.00	142.30	132.10	158.60	145.00	111.80	158.60	107.80	119.60	116.10
K1	104.00	68.30	100.00	158.40	242.30	175.40	206.40	185.70	135.60	238.50	144.10	114.40	226.60	95.70	111.80	137.10
K6	92.80	72.90	100.00	152.30	152.70	184.80	197.20	175.90	131.30	230.90	140.40	119.20	215.60	94.20	111.20	134.20
N4	84.20	39.30	100.00	174.50	127.40	155.60	167.60	151.90	157.80	183.30	141.90	113.60	173.90	95.90	107.90	126.30
K5	98.30	66.40	100.00	178.80	148.20	160.00	196.70	156.30	149.60	232.10	141.30	110.80	221.30	92.60	111.20	135.50
N1	81.20	51.90	100.00	150.70	127.00	152.20	169.30	148.80	135.40	187.70	141.40	149.40	176.70	96.00	111.80	127.10
BLANK-3	104.20	109.90	100.00	174.40	138.10	131.90	133.50	121.30	148.40	139.90	146.00	127.00	135.70	101.90	113.20	143.10
Reference-3	130.00	130.90	100.00	186.40	268.80	190.70	249.40	196.20	156.90	311.10	159.00	123.80	280.20	101.60	121.00	159.00
K4	110.30	75.80	100.00	249.70	155.80	180.50	224.00	173.70	208.60	275.00	148.40	120.40	257.30	99.10	120.50	143.90
K4	106.40	88.10	100.00	209.50	176.90	175.20	222.30	167.20	180.50	262.40	149.30	116.30	248.30	93.00	115.90	145.80
K2	50.20	23.00	100.00	79.30	55.20	88.10	105.00	86.30	69.40	132.70	104.30	57.20	122.90	45.90	82.80	96.60
K3	79.00	72.90	100.00	143.20	150.60	148.10	184.80	144.20	119.10	225.20	123.50	86.10	209.10	74.60	95.10	121.30
N2	79.20	85.10	100.00	136.30	148.20	133.30	151.80	130.90	110.50	172.20	119.00	89.90	163.80	74.20	91.20	118.00
A1	65.00	70.00	100.00	105.80	114.30	103.10	178.00	98.30	88.30	200.40	94.60	68.10	194.40	59.70	101.50	93.70
A2	95.20	94.30	100.00	108.20	112.80	106.90	128.00	99.60	90.50	141.70	146.80	103.80	137.70	91.30	111.40	128.20
A3	93.20	84.10	100.00	157.10	165.90	162.00	196.30	158.10	136.50	217.60	145.10	103.70	209.80	94.00	114.90	142.10
A4	114.20	86.80	100.00	151.70	172.90	155.50	181.20	149.30	132.10	201.30	141.20	141.50	193.20	90.60	107.40	133.70
A5	126.60	122.50	100.00	151.90	203.50	146.60	181.60	142.20	131.40	193.10	140.70	140.70	190.50	88.80	105.70	138.90
A6	130.80	125.10	100.00	159.30	169.60	155.40	191.30	143.00	137.00	200.60	148.20	169.80	196.50	108.90	121.10	147.10
A7	87.90	61.80	100.00	154.60	156.40	156.80	176.70	147.50	139.10	190.90	145.70	98.40	183.60	61.00	106.70	143.40
BLANK-4	98.80	107.10	100.00	108.50	126.00	97.90	106.60	95.10	87.90	114.10	143.40	103.40	110.50	93.70	108.70	142.60
Reference-4	107.10	117.50	100.00	172.90	216.10	180.30	230.80	181.80	140.90	289.60	213.60	112.20	266.50	101.60	117.80	152.40
A8	103.20	123.80	100.00	167.90	190.80	175.80	214.10	169.60	137.80	243.00	149.60	109.00	237.90	95.70	117.40	148.30
A8	139.80	154.00	100.00	165.90	194.10	173.30	209.00	172.50	139.00	230.40	145.90	136.10	223.40	90.30	112.60	145.50
A9	108.60	145.00	100.00	155.60	175.50	156.90	189.40	157.80	130.60	206.20	143.40	105.60	201.30	91.10	113.30	142.10
A10	114.80	136.00	100.00	213.50	160.30	154.10	183.80	153.90	158.80	197.70	142.50	105.30	194.00	94.30	113.90	138.60
S1	138.90	116.30	100.00	152.10	161.10	156.90	180.90	138.00	131.60	199.40	145.50	105.50	193.90	93.20	112.80	142.50
S2	145.50	135.90	100.00	152.40	171.40	151.90	181.20	144.70	130.00	285.30	143.00	153.60	281.40	95.70	113.40	140.80
S3	66.10	72.80	100.00	104.30	113.60	100.90	117.90	98.90	86.40	130.20	97.20	71.10	125.80	62.00	112.00	96.10
S4	111.40	147.10	100.00	161.80	180.00	160.60	185.20	161.50	135.80	209.00	144.20	108.50	201.50	95.50	113.60	143.90
S5	111.70	113.40	100.00	151.60	167.80	150.20	175.00	145.60	130.10	195.20	142.00	105.10	189.70	89.00	111.50	140.20
S6	82.80	76.60	100.00	133.50	140.00	135.20	231.60	135.50	111.70	259.40	126.30	105.50	249.30	83.50	120.40	122.00
S7	97.30	104.80	100.00	159.80	179.60	157.70	171.80	159.10	137.90	194.10	149.20	104.50	185.90	88.20	113.10	148.50
S8	99.20	102.30	100.00	156.70	175.20	160.30	175.40	158.70	130.70	198.10	146.60	106.30	191.40	91.10	112.70	146.70
S9	97.90	105.80	100.00	160.70	183.50	163.20	174.10	159.90	138.20	198.60	148.80	104.10	188.20	89.80	112.70	147.90
S10	94.10	100.90	100.00	155.10	171.10	151.40	164.00	142.50	132.30	181.80	147.60	101.30	173.30	88.70	111.00	146.60
BLANK-2	93.63	81.94	100.00	122.47	86.16	110.33	96.37	100.17	106.43	94.56	187.42	101.00	94.48	94.64	105.58	172.75
N3	94.96	54.08	100.00	136.20	109.19	144.65	151.02	142.33	132.08	158.59	145.02	111.80	158.56	107.78	119.61	116.14
K1	103.96	68.27	100.00	158.36	242.26	175.41	206.39	185.65	135.64	238.52	144.06	114.44	226.64	95.71	111.80	137.13
K6	92.78	72.86	100.00	152.35	152.69	184.79	197.21	175.87	131.27	230.93	140.40	119.20	215.61	94.23	111.21	134.24
N4	84.17	39.35	100.00	174.50	127.42	155.60	167.64	151.88	157.80	183.26	141.87	113.57	173.88	95.93	107.90	126.26
K5	98.32	66.42	100.00	178.79	148.23	159.96	196.66	156.34	149.62	232.12	141.33	110.81	221.26	92.65	111.22	135.48
N1	81.25	51.85	100.00	150.72	126.97	152.21	169.27	148.76	135.38	187.73	141.39	149.44	176.70	95.98	111.82	127.13
BLANK-3	104.22	109.89	100.00	174.35	138.08	131.92	133.49	121.31	148.40	139.90	146.03	127.02	135.74	101.90	113.20	143.12
K4	110.28	75.77	100.00	249.73	155.76	180.54	224.03	173.68	208.60	274.98	148.41	120.36	257.26	99.08	120.47	143.88
K4	106.35	88.14	100.00	209.48	176.86	175.21	222.28	167.25	180.50	262.38	149.32	116.30	248.31	92.96	115.86	145.84
K2	50.23	23.04	100.00	79.33	55.16	88.11	104.97	86.27	69.41	132.74	104.32	57.16	122.94	45.90	82.80	96.56
K3	78.97	72.89	100.00	143.21	150.57	148.13	184.79	144.23	119.09	225.22	123.46	86.10	209.08	74.65	95.10	121.30
N2	79.19	85.09	100.00	136.30	148.25	133.32	151.76	130.91	110.50	172.18	119.01	89.95	163.85	74.17	91.21	117.97
A1	64.99	70.01	100.00	105.78	114.25	103.09	177.97	98.34	88.32	200.37	94.62	68.10	194.45	59.74	101.49	93.65
A2	95.15	94.30	100.00	108.23	112.85	106.91	128.04	99.59	90.46	141.73	146.77	103.77	137.71	91.34	111.41	128.24
A3	93.23	84.15	100.00	157.10	165.93	162.03	196.26	158.15	136.55	217.55	145.11	103.72	209.78	94.02	114.92	142.10
A4	114.24	86.84	100.00	151.72	172.94	155.46	181.19	149.35	132.08	201.34	141.20	141.50	193.21	90.64	107.37	133.74
A5	126.57	122.54	100.00	151.90	203.47	146.60	181.56	142.16	131.38	193.08	140.66	140.67	190.53	88.79	105.66	138.85
A6	130.83	125.10	100.00	159.28	169.64	155.35	191.26	143.01	136.98	200.58	148.22	169.77	196.48	108.95	121.13	147.06
A7	87.86	61.77	100.00	154.56	156.35	156.77	176.66	147.49	139.14	190.90	145.73	98.45	183.63	60.99	106.65	143.43
BLANK-4	98.84	107.12	100.00	108.47	125.95	97.86	106.59	95.11	87.94	114.10	143.36	103.39	110.48	93.67	108.68	142.60
A8	103.20	123.80	100.00	167.94	190.79	175.77	214.06	169.65	137.81	242.98	149.64	109.04	237.89	95.71	117.44	148.28
A8	139.85	153.97	100.00	165.95	194.10	173.32	209.03	172.49	139.00	230.44	145.90	136.05	223.39	90.29	112.56	145.50
A9	108.57	144.98	100.00	155.57	175.48	156.92	189.37	157.84	130.61	206.21	143.42	105.63	201.35	91.12	113.33	142.12
A10	114.80	136.01	100.00	213.54	160.31	154.12	183.76	153.86	158.83	197.70	142.46	105.32	193.96	94.32	113.92	138.61
S1	138.89	116.28	100.00	152.14	161.15	156.95	180.89	138.01	131.62	199.42	145.51	105.45	193.93	93.17	112.85	142.51
S2	145.51	135.93	100.00	152.42	171.42	151.91	181.17	144.74	130.02	285.32	142.95	153.57	281.36	95.71	113.42	140.78
S3	66.14	72.76	100.00	104.30	113.62	100.89	117.89	98.90	86.43	130.23	97.16	71.10	125.80	62.01	111.99	96.15
S4	111.44	147.10	100.00	161.79	180.02	160.56	185.16	161.48	135.77	208.99	144.15	108.48	201.54	95.53	113.58	143.94
S5	111.74	113.36	100.00	151.61	167.78	150.17	175.04	145.64	130.10	195.24	142.03	105.08	189.72	88.97	111.52	140.20
S6	82.84	76.63	100.00	133.50	139.96	135.25	231.59	135.52	111.75	259.36	126.29	105.49	249.34	83.51	120.37	122.03
S7	97.29	104.83	100.00	159.76	179.65	157.72	171.77	159.06	137.86	194.08	149.25	104.54	185.91	88.20	113.08	148.53
S8	99.16	102.27	100.00	156.74	175.18	160.28	175.38	158.70	130.70	198.07	146.58	106.29	191.43	91.13	112.67	146.67
S9	97.87	105.84	100.00	160.71	183.48	163.17	174.13	159.88	138.22	198.57	148.76	104.08	188.24	89.77	112.72	147.91
S10	94.08	100.88	100.00	155.10	171.10	151.40	164.03	142.50	132.28	181.76	147.62	101.33	173.30	88.69	110.98	146.58
BLANK-2	93.63	81.94	100.00	122.47	86.16	110.33	96.37	100.17	106.43	94.56	187.42	101.00	94.48	94.64	105.58	172.75
BLANK-3	104.22	109.89	100.00	174.35	138.08	131.92	133.49	121.31	148.40	139.90	146.03	127.02	135.74	101.90	113.20	143.12
BLANK-4	98.84	107.12	100.00	108.47	125.95	97.86	106.59	95.11	87.94	114.10	143.36	103.39	110.48	93.67	108.68	142.60
Reference-2	71.81	73.93	100.00	117.46	129.61	118.06	158.10	119.06	97.65	193.05	102.54	83.98	173.28	68.18	113.27	101.18
Reference-3	129.98	130.87	100.00	186.35	268.81	190.70	249.45	196.19	156.86	311.12	158.99	123.82	280.17	101.62	120.99	158.95
Reference-4	107.13	117.54	100.00	172.93	216.14	180.29	230.83	181.76	140.93	289.57	213.56	112.19	266.50	101.62	117.78	152.37
N3	94.96	54.08	100.00	136.20	109.19	144.65	151.02	142.33	132.08	158.59	145.02	111.80	158.56	107.78	119.61	116.14
NAT-5	112.14	114.77	100.00	147.71	150.67	215.03	162.00	207.44	128.08	171.23	138.80	141.37	166.41	92.75	110.87	137.13
NAT-5	95.33	93.86	100.00	149.63	159.46	149.27	167.03	137.97	127.50	180.45	138.03	102.45	174.63	90.33	131.91	136.15
K1	103.96	68.27	100.00	158.36	242.26	175.41	206.39	185.65	135.64	238.52	144.06	114.44	226.64	95.71	111.80	137.13
K6	92.78	72.86	100.00	152.35	152.69	184.79	197.21	175.87	131.27	230.93	140.40	119.20	215.61	94.23	111.21	134.24
N4	84.17	39.35	100.00	174.50	127.42	155.60	167.64	151.88	157.80	183.26	141.87	113.57	173.88	95.93	107.90	126.26
NAT-1	84.13	87.34	100.00	131.41	143.10	132.31	148.96	117.87	111.49	172.20	120.43	88.76	161.73	79.54	109.92	118.79
NAT-3	69.23	69.08	100.00	118.62	124.03	117.92	137.19	116.05	94.21	164.34	103.10	76.19	154.13	65.41	118.30	101.80
K5	98.32	66.42	100.00	178.79	148.23	159.96	196.66	156.34	149.62	232.12	141.33	110.81	221.26	92.65	111.22	135.48
N1	81.25	51.85	100.00	150.72	126.97	152.21	169.27	148.76	135.38	187.73	141.39	149.44	176.70	95.98	111.82	127.13
K4	110.28	75.77	100.00	249.73	155.76	180.54	224.03	173.68	208.60	274.98	148.41	120.36	257.26	99.08	120.47	143.88
K4	106.35	88.14	100.00	209.48	176.86	175.21	222.28	167.25	180.50	262.38	149.32	116.30	248.31	92.96	115.86	145.84
K2	50.23	23.04	100.00	79.33	55.16	88.11	104.97	86.27	69.41	132.74	104.32	57.16	122.94	45.90	82.80	96.56
K3	78.97	72.89	100.00	143.21	150.57	148.13	184.79	144.23	119.09	225.22	123.46	86.10	209.08	74.65	95.10	121.30
N2	79.19	85.09	100.00	136.30	148.25	133.32	151.76	130.91	110.50	172.18	119.01	89.95	163.85	74.17	91.21	117.97
NAT	97.83	107.77	100.00	146.55	160.89	147.44	175.85	144.70	119.28	206.28	127.27	130.13	217.09	80.51	101.60	126.65
NAT	78.06	84.82	100.00	142.12	146.46	146.65	164.85	141.49	119.29	191.35	126.62	87.72	182.62	76.34	94.77	124.13
A1	64.99	70.01	100.00	105.78	114.25	103.09	177.97	98.34	88.32	200.37	94.62	68.10	194.45	59.74	101.49	93.65
A2	95.15	94.30	100.00	108.23	112.85	106.91	128.04	99.59	90.46	141.73	146.77	103.77	137.71	91.34	111.41	128.24
A3	93.23	84.15	100.00	157.10	165.93	162.03	196.26	158.15	136.55	217.55	145.11	103.72	209.78	94.02	114.92	142.10
A4	114.24	86.84	100.00	151.72	172.94	155.46	181.19	149.35	132.08	201.34	141.20	141.50	193.21	90.64	107.37	133.74
A5	126.57	122.54	100.00	151.90	203.47	146.60	181.56	142.16	131.38	193.08	140.66	140.67	190.53	88.79	105.66	138.85
A6	130.83	125.10	100.00	159.28	169.64	155.35	191.26	143.01	136.98	200.58	148.22	169.77	196.48	108.95	121.13	147.06
A7	87.86	61.77	100.00	154.56	156.35	156.77	176.66	147.49	139.14	190.90	145.73	98.45	183.63	60.99	106.65	143.43
A8	103.20	123.80	100.00	167.94	190.79	175.77	214.06	169.65	137.81	242.98	149.64	109.04	237.89	95.71	117.44	148.28
A8	139.85	153.97	100.00	165.95	194.10	173.32	209.03	172.49	139.00	230.44	145.90	136.05	223.39	90.29	112.56	145.50
A9	108.57	144.98	100.00	155.57	175.48	156.92	189.37	157.84	130.61	206.21	143.42	105.63	201.35	91.12	113.33	142.12
A10	114.80	136.01	100.00	213.54	160.31	154.12	183.76	153.86	158.83	197.70	142.46	105.32	193.96	94.32	113.92	138.61
S1	138.89	116.28	100.00	152.14	161.15	156.95	180.89	138.01	131.62	199.42	145.51	105.45	193.93	93.17	112.85	142.51
S2	145.51	135.93	100.00	152.42	171.42	151.91	181.17	144.74	130.02	285.32	142.95	153.57	281.36	95.71	113.42	140.78
S3	66.14	72.76	100.00	104.30	113.62	100.89	117.89	98.90	86.43	130.23	97.16	71.10	125.80	62.01	111.99	96.15
S4	111.44	147.10	100.00	161.79	180.02	160.56	185.16	161.48	135.77	208.99	144.15	108.48	201.54	95.53	113.58	143.94
S5	111.74	113.36	100.00	151.61	167.78	150.17	175.04	145.64	130.10	195.24	142.03	105.08	189.72	88.97	111.52	140.20
S6	82.84	76.63	100.00	133.50	139.96	135.25	231.59	135.52	111.75	259.36	126.29	105.49	249.34	83.51	120.37	122.03
S7	97.29	104.83	100.00	159.76	179.65	157.72	171.77	159.06	137.86	194.08	149.25	104.54	185.91	88.20	113.08	148.53
S8	99.16	102.27	100.00	156.74	175.18	160.28	175.38	158.70	130.70	198.07	146.58	106.29	191.43	91.13	112.67	146.67
S9	97.87	105.84	100.00	160.71	183.48	163.17	174.13	159.88	138.22	198.57	148.76	104.08	188.24	89.77	112.72	147.91
S10	94.08	100.88	100.00	155.10	171.10	151.40	164.03	142.50	132.28	181.76	147.62	101.33	173.30	88.69	110.98	146.58

Table 21a: Summary of regression models examining the relationship between the concentrations of antioxidants (TAnC, TPC, Vitamin C, TAC, and TAA) in pin cherry fruit samples (SS1, SS2, RS1) and PC1-4, representing pin cherry samples.

		TAnC	TPC	VitaminC	TAA	TAC
R^2		0.20962765	0.2088353	0.14212258	0.23916099	0.39193401
F		3.0501041	3.03553224	1.90517853	3.6148928	7.41242096
Pr > F		0.067	0.068	0.172	0.043	0.003
PC1	F					
	Pr > F					
PC2	F		1.07564473	1.5967684	0.76559456	11.2890025
	Pr > F		0.310	0.219	0.391	0.003
PC3	F	2.569333		2.21358865		
	Pr > F	0.123		0.150		
PC4	F	3.5308752	4.99541975		6.46419103	3.53583944
	Pr > F	0.073	0.035		0.018	0.073

Table 21b: Regression model examining the relationship between the concentrations of TAC in pin cherry fruit samples (SS1, SS2, RS1) and PC1-4 representing pin cherry samples.

Source	Standardized Coefficients Beta (Std. Error)	Significance	ANOVA regression significance
Intercept	0.938 (0.020)	<0.0001	**0.003**
PC1	0.000 (0.000)		
PC2	**-0.015 (0.005)**	**0.003**	
PC3	0.000 (0.000)		
PC4	-0.013 (0.007)	0.073	
Dependent: TAC			

Table 21c: Regression model examining the relationship between the concentrations of TAA in pin cherry fruit samples (SS1, SS2, RS1) and PC1-4 representing pin cherry samples.

Source	Standardized Coefficients Beta (Std. Error)	Significance	ANOVA regression significance
Intercept	1.124 (0.064)	<0.0001	**0.043**
PC1	0.000 (0.000)		
PC2	-0.013 (0.015)	0.391	
PC3	0.000 (0.000)		
PC4	**0.058 (0.023)**	**0.018**	
Dependent: TAA			

Table 22a: Summary of regression models examining the relationship between the concentrations of antioxidants (TAnC, TPC, Vitamin C, TAC, and TAA) in blueberry fruit samples (SS3, RS2) and PC1-4, representing blueberry samples.

		TAnC	TAC	TPC	VitaminC	TAA
R^2		0.28251513	0.21564341	0.6103978	0.18560559	0.21287215
F		2.36254566	1.64958196	9.40032371	1.36743759	1.62264987
Pr > F		0.136	0.233	0.003	0.292	0.238
PC1	F	3.43074247		11.507440 3		2.12852274
	Pr > F	0.089		0.005		0.170
PC2	F		0.63691136			
	Pr > F		0.440			
PC3	F	1.29434886	2.66225256	7.29320708	1.00151962	
	Pr > F	0.277	0.129	0.019	0.337	
PC4	F				1.73335556	1.116777
	Pr > F				0.213	0.311

Table 22b: Regression model examining the relationship between the concentrations of TPC in blueberry fruit samples (SS3, RS2) and PC1-4 representing blueberry samples.

Source	Standardized Coefficients Beta (Std. Error)	Significance	ANOVA regression significance

Intercept	10.578 (0.313)	<0.0001	
PC1	**-0.190 (0.056)**	**0.005**	
PC2	0.000 (0.000)		**0.003**
PC3	**0.220 (0.082)**	**0.019**	
PC4	0.000 (0.000)		
Dependent: TPC			

Table 23a: Fruit Quality Correlations in pin cherry fruit samples (SS1, SS2, RS1).

Variables	TAnC	TPC	VitaminC	pH	TAA	TAC	WC
TAnC	**1**	**0.508**	-0.165	0.138	**-0.494**	**0.488**	-0.198
TPC	**0.508**	**1**	0.025	0.055	**-0.545**	**0.467**	-0.286
VitaminC	-0.165	0.025	**1**	**-0.391**	-0.083	**-0.392**	0.380
pH	0.138	0.055	**-0.391**	**1**	0.146	**0.663**	**-0.669**
TAA	**-0.494**	**-0.545**	-0.083	0.146	**1**	-0.227	0.122
TAC	**0.488**	**0.467**	**-0.392**	**0.663**	-0.227	**1**	**-0.499**
WC	-0.198	-0.286	0.380	**-0.669**	0.122	**-0.499**	**1**

Values in bold have a p-value < 0.05 (= significant)

Table 23b: Fruit Quality Correlations in blueberry fruit samples (SS3, RS2).

Variables	TAnC	TAC	TPC	VitaminC	pH	TAA	WC
TAnC	**1**	-0.088	**0.869**	0.428	0.002	**-0.957**	-0.001
TAC	-0.088	**1**	-0.151	-0.031	0.115	0.134	-0.167
TPC	**0.869**	-0.151	**1**	0.334	0.017	**-0.825**	0.040
VitaminC	0.428	-0.031	0.334	**1**	-0.290	**-0.519**	-0.346
pH	0.002	0.115	0.017	-0.290	**1**	0.079	0.409
TAA	**-0.957**	0.134	**-0.825**	**-0.519**	0.079	**1**	0.020
WC	-0.001	-0.167	0.040	-0.346	0.409	0.020	**1**

Values in bold have a p-value < 0.05 (= significant)

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