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RESEARCH ARTICLE OPEN ACCESS

Mineral Composition of Blackcurrant (*Ribes Nigrum* L.) Fruits and Leaves

Oksana Struk[1], Galyna Starchenko[1], Oleh Koshovyi[2,3], Oleksandr Stremoukhov[4], Yurii Klymenko[5] and Ain Raal[2,*]

[1]*Department of Pharmaceutical Management, Drug Technology and Pharmacognosy, Ivano-Frankivsk National Medical University, Ivano-Frankivsk, Ukraine*

[2]*Institute of Pharmacy, Faculty of Medicine, University of Tartu, Tartu, Estonia*

[3]*Department of Pharmacognosy, The National University of Pharmacy, Kharkiv, Ukraine*

[4]*Department of Socio-Humanitarian and Biomedical Sciences, Kharkiv Institute of Medicine and Biomedical Sciences, Kharkiv, Ukraine*

[5]*Department of Surgery and Cardio Surgery, Ivano-Frankivsk National Medical University, Ivano-Frankivsk, Ukraine*

Abstract:

Background: Plants as living systems are characterized by the appropriate degree of accumulation of macro- and microelements, which, acting as factors of the external environment, are basic modulators for synthesizing biologically active substances. Blackcurrant (*Ribes nigrum* L., *Grossulariaceae*) is widespread worldwide. Berries, leaves, and buds are medicinal raw materials in folk medicine. The regularity of inorganic elements accumulation in this plant and their impact on the quality of raw materials are topical and need to be studied.

Aims: This work aimed to study the mineral composition of *R. nigrum* raw materials collected in Western Ukraine (Ivano-Frankivsk and Ternopil regions) and find the regularity of their accumulation in the plant parts and from the soils.

Methods: The elemental compositions of *R. nigrum* fruits and leaves, as well as the soils of the growth places, were studied using the method of atomic emission spectrometry with inductively coupled plasma iCAP 7000 Duo.

Results: The content of 19 inorganic elements in *R. nigrum* raw materials was established. Their quantities don't differ significantly depending on the growth places. All the fruits had high K, Na, Mg, P, and Ca contents, which were slightly lower in leaves. Thus, the fruits contain 590-675 mg/kg of Mg, while in leaves, there are just 98-106 mg/kg. Most of Fe was accumulated in the fruits (73-85 mg/kg). The content of Mn was observed in the leaves (57-64 mg/kg), slightly higher than in the fruits (47-51 mg/kg). The content of heavy metals in the objects was within the permitted limits of European Pharmacopeia. The results testify to the inverse relationship between the content of most elements in the soils and the coefficient of their accumulation in the plant.

Conclusion: The content of macro- and microelements in *R. nigrum* fruits and leaves had similar profiles but differed in their quantitates. The regularity of element accumulation in *R. nigrum* raw materials corresponds to the following profile in accordance with their quantitative content in the raw materials: K> Na> P> Mg> Ca> Si> Fe> Mn> Al> Se> Zn> Cu> Co> I> Pb> Ni> Mo> Sr> Cd. The regularity of their accumulation in the plant parts from the soils was established.

Keywords: Blackcurrant, Inorganic elements, Heavy metals, Macroelements, Microelements, Soil.

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*Address correspondence to this author at the Institute of Pharmacy, Faculty of Medicine, University of Tartu, Nooruse 1 Tartu, 50411, Estonia; Tel: +372 7375288;
Fax: +372 7375289; E-mail: ain.raal@ut.ee

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1. INTRODUCTION

Macro- and microelements, as biotics, have an essential role in maintaining homeostasis in the human body and determining the influence on the processes of hematopoiesis, tissue respiration, immune reactions, cell division, growth, reproduction, and the function of endocrine glands. The deficiency or excess of certain elements causes the formation of a pathological process in the body. Medicinal plants are an important source of mineral compounds, in which macro- and microelements accumulate in complexes in the most favourable ratio of the main components and the most accessible and digestible form for the human and animal body [1-4].

Plant organisms as living systems are characterized by the appropriate degree of accumulation of macro- and microelements, which act as factors of the external environment. Inorganic elements play the role of main modulators for the synthesis of organic molecular structures and biologically active substances. The elements make it possible to follow the migration of inorganic compounds in the biosphere and to determine the most favourable places for harvesting raw materials from an ecological point of view [1, 5-7].

Therefore, an urgent issue of modern pharmacy is the research and development of new medicines containing a complex of necessary macro- and microelements. At the same time, depending on the place of growth, plants can accumulate harmful or toxic substances for the body, which must be considered when harvesting and growing plants and in their standardization [8-11].

Ribes nigrum L. belongs to the family *Grossulariaceae*. The berries of *R. nigrum* were first collected from wild plants for medicinal use, and since the 16th century, they have been cultivated all over Europe. One of the first regions where *R. nigrum* started to be cultivated actively was the Kingdom of England. The history of blackcurrant cultivation in Europe is connected with its use for culinary and medical purposes [12, 13]. Nowadays *R. nigrum* is widespread in Western Europe, Ukraine, Kazakhstan, Russia, Mongolia, and China as a wild plant. It grows on the banks of rivers and lakes and can form large thickets. Cultivated as a berry bush for industrial purposes and in private plots. Berries of *R. nigrum* are used in food in fresh form, as well as for making juices, jams, pastilles, *etc* [14-16].

Medicinal plant raw materials of *R. nigrum* are mainly fruits, as well as leaves and shoots. Berries ripen in July-August, are dried in dryers at up to 35°C, and stored in bags or wooden containers. Fresh berries are stored in the refrigerator for 5-6 days. Shoots are harvested in early spring or winter [15-17].

The fresh *R. nigrum* berries consist of water (81.3%), dietary fiber (6.78%), carbohydrates (6.11%), organic acids (2.63%), proteins (1.28%), minerals (0.80%), and fat (0.22%). They are very rich in vitamins, such as vitamin C (up to 181 mg per 100 g of fresh berries), K (less than 10 μg per 100 g of fresh berries), B groups (B_1, B_2, B_5, B_6), and an insignificant content of vitamins A and E, but their amount can change [14, 15, 18, 19].

Berries, leaves, and buds are medicinal raw materials in folk medicine. The leaves and buds have anti-inflammatory and diuretic effects and are used as homeopathic remedies. Leaves and fruits treat urolithiasis, cystitis, gout, rheumatism, osteochondrosis, muscle and joint pain, eczemas, and furunculosis. The *R. nigrum* leaves are part of the vitamin collection with raspberry leaves, rose hips, and wild strawberry leaves [14, 16,17, 20].

This work aims to study the mineral composition of *R. nigrum* raw materials collected in Ivano-Frankivsk and Ternopil regions of Ukraine and find the regularity of their accumulation in the plant parts and from the soils.

2. MATERIALS AND METHODS

2.1. Materials

The 4 samples of *R. nigrum* fruits and leaves (100 g of each raw materials), harvested in the Ivano-Frankivsk (Nadvirnyansky district, the outskirts of Tsutsiliv (48.732426, 24.633221) and Delyatyn (48.516048, 24.612000) villages; Tysmenytskyi district, outskirts of the Wovchynts village (48.953045, 24.753404)) and Ternopil regions (outskirts of Monastyrisk city (49.102284, 25.162038)) in 2021. The identity of the plant was established with the consulting assistance of Professor A.R. Grytsyk from the Ivano-Frankivsk National Medical University (IFNMU), according to the botanical catalogue [21]. Voucher specimens No. 512–517 were deposited at the Department of Pharmaceutical Management, Drug Technology and Pharmacognosy, Ivano-Frankivsk National Medical University, Ukraine.

The fruits of *R. nigrum* were harvested fully ripe, had a rich colour, and were dried in a dryer at a temperature of 40°. Fruit drying was carried out until the berries became crumbly and easily broken. The leaves of *R. nigrum* were harvested during the plant's flowering period. Young fresh leaves were harvested in the morning before exposure to the sun. Leaves were collected from different plants in small quantities so that the plants could continue to grow. The leaves were dried in a dryer at a temperature below 40°C.

Soil samples were taken from at least 10 to 20-point samples from *R. nigrum* growth sites by the "envelope" method [22] to determine the macro- and microelement composition. Samples were taken layer by layer from a depth of 0-5 cm and 5-20 cm weighing no more than 200 g each with a metal-free tool.

2.2. Atomic Emission Spectrometry

The elemental compositions of *R. nigrum* raw material and soils were studied based on the State Enterprise "Ivano-Frankivsk Scientific Production Center for Standardization, Metrology and Certification" (accreditation certificate No. 2H098 dated June 20, 2014.) by the method of atomic emission spectrometry with inductively coupled plasma iCAP 7000 Duo [23-25].

Sample preparation involved homogenization, weighing, addition of nitric acid, and transfer of the corresponding sample to a microwave oven according to SSTU [25]. Under the influence of the given parameters of pressure and temperature, samples weredecomposed. The resulting samples were diluted with deionized water and introduced into an inductively coupled plasma atomic emission spectrometer, which includes a computer-controlled background-corrected atomic emission spectrometer, a radio frequency generator, and an argon supply system. Atomic emission was measured using optical spectroscopy. The samples were sprayed, and the formed aerosol was transported to the plasma torch, where excitation occurs. Characteristic atomic emission lines weregenerated by radio frequency inductively coupled plasma. The measurement spectrum wasdistributed on the diffraction grating of the spectrometer, and the detector recorded the intensity of the lines. The signals from the detectors were monitored and processed by a computer [25-27].

To identify the influence of growing conditions on the content of inorganic elements in *R. nigrum* raw materials, their quantitative determination was carried out in soils and fruits from different places of growth. In the selected samples, the content of moving forms macro- (Mg, Fe) and microelements (Cu, Zn, Mn, Co, Cr, B, and Cd) was determined. Their choice is due to the fact that most of them are biophilic elements important for plant vital processes [24].

To find out the intensity of absorption of macro- and microelements by plants from the soil, are calculated the Coefficients of their Biological Accumulation (CBA) according to the formula:

CBA = element content in a sample of medicinal plant raw materials,mg/kg / element content in the soil,mg/kg

About the absorption of macro- and microelements from the soil by plants, draw a conclusion based on the coefficient of biological accumulation: if CBA < 1, then this indicates a low level of absorption of a certain element by the plant from the soil [24].

3. RESULTS

We determined the elemental composition (Table **1**) of *R. nigrum* fruits and leaves and established the presence of 19 macro- and microelements. We quantitatively determined 13 elements, including K, Na, P, Mg, Ca, Si, Fe, Mn, Se, Zn, Cu, and Co, and traces of 8 elements (I, Pb, Ni, Mo, Sr, Cd).

The results of the study of the content of inorganic elements in soils and *R. nigrum* fruits from different places of growth are presented in Table **2**.

Table 1. The content of macro- and microelements in *ribes nigrum* fruits and leaves from different places of growth.

Element	Content of Elements (mg/kg) in *Ribes Nigrum* Raw Material							
	Nadvirnyansky District, the Outskirts of Tsutsiliv Village		Ivano-Frankivsk Region, Nadvirnyansky District, Delyatyn Village		Ivano-Frankivsk Region, Tysmenytskyi District, Outskirts of the Wovchyntsi Village		Ternopil Region, the Outskirts of Monastyrisk City	
	Fruits	Leaves	Fruits	Leaves	Fruits	Leaves	Fruits	Leaves
Macroelements								
K	3550.00	1070.00	3100.00	890.00	3622.00	1190.00	3094.00	911.00
Na	1830.00	840.00	1760.00	760.00	1890.00	870.00	1670.00	690.00
P	1010.00	600.00	840.00	510.00	960.00	540.00	840.00	460.00
Mg	650.00	106.00	590.00	98.00	675.00	111.00	596.00	101.00
Ca	642.00	117.00	486.00	93.00	648.00	126.00	610.00	122.00
Si	471.00	56.00	399.00	51.00	486.00	69.00	406.00	64.00
Fe	79.00	43.00	73.00	38.00	88.00	51.00	85.00	49.00
Microelements								
Mn	51.00	64.00	47.00	59.00	49.00	61.00	50.00	57.00
Al	73.00	19.20	65.00	19.80	84.00	20.10	71.00	18.60

(Table 1) contd.....

Element	Content of Elements (mg/kg) in *Ribes Nigrum* Raw Material							
	Nadvirnyansky District, the Outskirts of Tsutsiliv Village		Ivano-Frankivsk Region, Nadvirnyansky District, Delyatyn Village		Ivano-Frankivsk Region, Tysmenytskyi District, Outskirts of the Wovchyntsi Village		Ternopil Region, the Outskirts of Monastyrisk City	
	Fruits	Leaves	Fruits	Leaves	Fruits	Leaves	Fruits	Leaves
Se	52.00	12.20	56.00	9.90	59.00	10.60	49.00	10.00
Zn	13.00	2.20	9.60	1.60	12.40	8.60	8.20	4.30
Cu	1.60	7.70	1.10	4.30	2.40	6.20	1.90	5.90
Co	12.60	3.52	11.10	2.90	10.40	2.40	9.50	1.90
I	<0.0002	<0.0001	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Pb	<0.0003	<0.0001	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Ni	<0.0001	<0.0001	<0.0002	<0.0002	<0.0002	-	<0.0002	<0.0002
Mo	<0.0003	-	<0.0002	<0.0002	-	-	<0.0002	<0.0002
Sr	<0.0001	<0.0001	<0.0002	<0.0002	<0.0001	<0.0001	<0.0001	<0.0001
Cd	<0.0001	<0.0001	<0.0002	<0.0002	<0.0001	<0.0001	<0.0002	<0.0002

Table 2. Study of the content of inorganic elements in soils and *ribes nigrum* fruits from different places of growth.

Element	Content of Elements (mg/kg) in *Ribes Nigrum* Raw Material and Soils							
	Nadvirnyansky District, the Outskirts of Tsutsiliv Village		Ivano-Frankivsk Region, Nadvirnyansky District, Delyatyn Village		The ivano-Frankivsk Region, Tysmenytskyi district, Outskirts of the Wovchyntsi Village		Ternopil Region, the outskirts of Monastyrisk City	
	Fruits	Soil	Fruits	Soil	Fruits	Soil	Fruits	Soil
Mg	650.00	70.77	590.00	51.14	675.00	54.33	596.00	67.45
Mn	51.00	13.48	47.00	12.33	49.00	14.11	50.00	10.32
Fe	79.00	48.10	73.00	39.23	88.00	40.45	85.00	42.00
Zn	13.00	57.23	9.60	47.65	12.40	50.90	8.20	55.87
Ba	-	64.44	-	59.23	-	62.06	-	60.51
Cu	1.60	5.90	1.10	7.77	2.40	7.45	1.90	6.00
Cr	-	22.11	-	17.11	-	19.35	-	22.70
B	-	0.84	-	0.64	-	0.82	-	0.96
Li	-	2.34	-	2.06	-	2.34	-	2.56
Co	12.60	1.34	11.10	1.56	10.40	1.72	9.50	1.90
Cd	<0.0001	1.81	<0.0002	1.59	<0.0001	1.78	<0.0002	1.78

Table 3. The coefficient of biological accumulation (CBA) of inorganic elements by *Ribes nigrum* fruits from different places of growth.

Element	CBA			
	Nadvirnyansky District, the Outskirts of Tsutsiliv Village	Ivano-Frankivsk Region, Nadvirnyansky District, Delyatyn Village	Ivano-Frankivsk Region, Tysmenytskyi District, Outskirts of the Wovchyntsi Village	Ternopil Region, the Outskirts of Monastyrisk City
Mg	9.19	12.55	12.42	8.84
Mn	3.78	3.81	3.47	4.85
Fe	1.64	1.86	2.18	2.02
Zn	0.23	0.20	0.24	0.15
Ba	0	0	0	0
Cu	0.27	0.14	0.32	0.32
Cr	0	0	0	0
B	0	0	0	0
Li	0	0	0	0
Co	9.40	7.12	6.05	5.00
Cd	0	0	0	0

We conducted a study of the Coefficient of Biological Accumulation (CBA) of inorganic elements, which made it possible to determine the direct dependence of elements in the soil and the coefficient of their accumulation in *R. nigrum* fruits (Table **3**).

A comparative analysis of the content of elements in the soils of Ivano-Frankivsk and Ternopil regions and the coefficient of biological accumulation of these elements in *R. nigrum* fruits from different places of growth allowed to establish the peculiarities of the dependence between these indicators.

4. DISCUSSION

The content of macro- and microelements (Table **1**) in *R. nigrum* raw materials, harvested from different growth places does not differ significantly. All fruit samples of *R. nigrum* had a high content of K, Na, Mg, P, and Ca, and it was slightly lower in leaves. The quantitative content of macro- and microelements in *R. nigrum* fruits and leaves had the same profile but differed in quantitative content. As a result of the research, we found that the *R. nigrum* fruits accumulate a more significant number of inorganic elements than the leaves.

The highest content of elements is found in the *R. nigrum* fresh fruits, in particular K, Na, P, Mg, Ca, Fe, and Mn, which are necessary for the vital activity of the body. They participate in metabolism and the formation of enzymes and hormones [28-30]. An imbalance of the elements of a living organism leads to the development of pathological processes.

The highest K content was observed in *R. nigrum* fruits (3094 – 3622 mg/kg), depending on the place of growth. In *R. nigrum* leaves, the content of K was lower (890 – 1190 mg/kg). Essential macronutrient potassium (K) and environmental signal light regulate many vital plant biological processes related to growth, development, and stress response [31]. Potassium homeostasis has a very high priority because of its importance for membrane potential. Multiple systems interface to accomplish fine K^+ balance and the consequences for health and disease [29, 32, 33]. The highest content of Na was found in *R. nigrum* fruits, harvested in the Ivano-Frankivsk region, Tysmenytsia district, near Wovchyntsi village (1890 mg/kg). The content of P ranged from 840 – 1100 mg/kg in fruits and 410 – 600 mg/kg in leaves, respectively. The Mg content in fruits was 590 – 675 mg/kg, and in leaves – 98 – 106 mg/kg. Magnesium is the fourth most abundant mineral and the second most abundant intracellular divalent cation and has been recognized as a cofactor for >300 metabolic reactions in the body [34]. There is an association between magnesium (Mg) and sleep health [35]. Magnesium also plays a critical role in nerve transmission, cardiac excitability, neuromuscular conduction, muscular contraction, vasomotor tone, blood pressure, and glucose and insulin metabolism [36-38]. The highest content of Ca was found in *R. nigrum* fruits (from 486 to 648 mg/kg of raw material). The content of Si in *R. nigrum* fruits was 399 – 486 mg/kg, and in the leaves – 51 – 69 mg/kg, according to the place of growth. Most of the Fe was accumulated in *R. nigrum* fruits and was 73 – 85 mg/kg in the raw material. The content of Mn was observed in leaves slightly higher than in fruits and ranged from 57 – 64 mg/kg. Manganese is an essential dietary element that functions primarily as a coenzyme in several biological processes. These processes include but are not limited to, macronutrient metabolism, bone formation, free radical defense systems, and, in the brain, ammonia clearance and neurotransmitter synthesis [39-41].

The quantitative content of macro- and microelements (Table **1**) in *R. nigrum* raw material had the same profile but different quantitative content. The regularity of the accumulation of elements in *R. nigrum* raw materials corresponds to the following profile in accordance with their quantitative content in the raw materials: K> Na> P> Mg> Ca> Si> Fe> Mn> Al> Se> Zn> Cu> Co> I> Pb> Ni> Mo> Sr> Cd.

The content of heavy metals in the investigated objects was within the permitted limits (State Pharmacopoeia of Ukraine 2.0 – 2.4.27) [22, 42, 43].

The content of inorganic elements (Table **2**) in *R. nigrum* fruits harvested from different growth places had the same profile, and the quantitative content did not differ significantly. All fruit samples showed a high content of Mg [44] and minor fluctuations in the level of other elements, which indicates the absence of an influence of the place of growth on the content of elements in *R. nigrum* fruits.

The results, which presented in Table **3**, testify to the inverse relationship between the content of most elements in the soil and the coefficient of their accumulation in plants. Such data are available for *Solanum nigrum* L., *Bidens pilosa* L., *Xanthium strumarium* L., *Helianthus annuus* L., *Lonicera japonica* T. and *Pennisetum sinese* R [45]. The phytoextraction pattern in 15 potential native plants growing on sludge showed that the *Blumea lacera*, *Parthenium hysterophorous*, *Setaria viridis*, *Chenopodium album* [46], *Cannabis sativa*, *Basella alba*, *Tricosanthes dioica*, *Amaranthus spinosus* L., *Achyranthes* sp., *Dhatura stramonium*, *Sacchrum munja,* and *Croton bonplandianum* were noted as root accumulator for Fe, Zn and Mn [4547], while *S. munja*, *P. hysterophorous*, *C. sativa, C. album*, *T. dioica*, *D. stramonium*, *B. lacera*, *B. alba*, *Kalanchoe pinnata* and *Achyranthes* sp. were found as shoot accumulator for Fe. In addition, *A. spinosus* was found as a shoot accumulator for Zn and Mn [48-53], but there is a lack of information about *R. nigrum.* It was established that at a low level of Mg in all soil samples, plants accumulated a significant amount of this element. The CBA ranged from 8.84 to 12.55, depending on the place of growth. The content of Mn and Fe in the soils from different harvesting sites was lower than in *R. nigrum* L. fruits, which indicates a significant accumulation of these elements by plants from the soil.

The content of Zn and Cu in the soils was significantly higher than in *R. nigrum* fruits. The CBA of these elements was lower than 1, which indicates a low level of absorption of these elements by plants from the soil. The Ba, Cr, B, and Li content was significant in the soils from where the plant grew, but it was not detected in *R. nigrum* fruits.

Based on the conducted research, in different growth conditions, plants specifically absorb biochemical elements from the soil on which they grow and can also absorb a certain element to a limited extent at its high concentration in the soil or not accumulate at all [54, 55]. But sometimes, the extensive use of chemical fertilizers rich in elements in some crops deteriorates soil health, which, in turn, affects productivity [56-58].

The content of macro- and microelements in the raw materials of *Ribes nigrum* L. harvested from different places of growth does not differ significantly. High K, Na, Mg, P, and Ca contents were observed in all samples of *Ribes nigrum* L. fruits, while it was slightly lower in leaves. The quantitative content of inorganic elements in the fruits and leaves of *Ribes nigrum* L. had the same profile but differed in quantitative content. As a result of the research, we established that the fruits of *Ribes nigrum* L. accumulate a larger amount of inorganic elements than in the leaves. We determined the elemental composition of the fruits and leaves of *Ribes nigrum* L.. We established the presence of 19 inorganic elements. 13 elements were quantified, including K, Na, P, Mg, Ca, Si, Fe, Mn, Se, Zn, Cu and Co and traces of 8 elements (I, Pb, Ni, Mo, Sr, Cd). The highest content of elements was determined in the fresh fruits of *Ribes nigrum* L., namely K, Na, P, Mg, Ca, Fe, and Mn, which are necessary for the vital activity of the body, in particular, they participate in metabolism, the formation of enzymes, hormones. An imbalance of the elements of a living organism leads to the development of pathological processes.

CONCLUSION

This study showed a high level of mineral substances in the analyzed fruits and leaves of *Ribes nigrum* L. Soil management systems and climatic conditions have a positive effect on plant development but do not have a significant impact on the accumulation of inorganic substances in the plant itself.

The quantitative content of macro- and microelements in *R. nigrum* raw material had the same profile but different quantitative content. The regularity of the accumulation of elements in *R. nigrum* raw materials corresponds to the following profile in accordance with their quantitative content in the raw materials: K> Na> P> Mg> Ca> Si> Fe> Mn> Al> Se> Zn> Cu> Co> I> Pb> Ni> Mo> Sr> Cd.

We studied the coefficient of biological accumulation of inorganic elements, which made it possible to establish an inverse relationship between the content of most elements in the soil and the coefficient of their accumulation in plants.

Based on the research, we conclude that in different growth conditions, plants specifically absorb biochemical elements from the soil on which they grow and absorb a specific component to a limited extent at its high concentration in the soil.

The results of our research are currently relevant. They must be considered in developing new medicinal products of plant origin, which would have previously desired pharmacological effects.

LIST OF ABBREVIATIONS

R.	=	Ribes
SSTU	=	State standard of Ukraine
CBA	=	The coefficients of their biological accumulation

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The data and supportive information are available within the article.

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CONFLICT OF INTEREST

Dr. Ain Raal is on the Editorial Advisory Board Member of The Open Agriculture Journal.

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