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Effects of Soil Chemistry on the Physico-Chemical Characteristics of the Grains of Adlay (*Coix lacryma-jobi* Linn) Grown in Bukidnon, Philippines

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ABSTRACT

The amounts of P, K, Ca, Mg, Na, Fe, Zn, Mn, Cu, B, Pb, and Cd in both grits and hull/testa of Adlay (*Coix lacryma-jobi* L., Gulian variety) in Bukidnon, Philippines, were quantified relative to the pH, electrical conductivity (EC), cation-exchange capacity (CEC), and amounts of organic matter (OM), N, P, K, Ca, Mg, Na, Fe, Zn, Mn, Cu, B, Pb, and Cd of the soils where these plants were grown. The P, K, Ca, Fe, and Cu contents in grits were differentiated by P, CEC, Ca, Fe, and Zn of the soil, respectively. The accumulations of both Mg and Zn in grits were influenced only by the pH of the soil while the Mn contents in grits were influenced by both pH and Mn content of the soil. The Fe, Zn, and B contents of hull/testa were significantly differentiated by the Zn, Fe and OM of the soil, respectively. The mean amounts of macro-elements in both grits and hull/testa were in the order of K>P>Mg>Ca. The mean micro-element contents in grits were in the order of Fe>Na>Mn>Zn>Cu>B, while for hull/testa, Fe>Na>Mn>Zn>B>Cu. The Pb contents in grits and hull/testa were below the detection limit of the method while the amounts of Cd in both grits and hull/testa were below the permitted maximum level of the Joint FAO/WHO Food Standards Programme-Codex Committee on Contaminants in Food. From the amounts of these elements in Adlay, this indigenous crop may well be a good alternative food crop for human and animal consumption.

Keywords: Coix lacryma-jobi L., Adlay, Micro-elements, Macro-elements, Lead, Cadmium

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INTRODUCTION

In attaining food sufficiency for its growing population, the national government of the Philippines mandated its sector the Department of Agriculture to look for a staple food substitute for rice and corn. The Department of Agriculture found the potential of the indigenous crop Adlay (*Coix lacryma-jobi* L.) as an alternative food crop. As a new crop, however, Adlay met some resistance among farmers not only with respect to the crop's economic viability but also on its nutrient quality.

There are already a lot of studies on Adlay in other countries like Japan, China and India which use Adlay not only as food and feed, but also as food additive, pharmaceutic, and cosmetic necessity with a lot of medicinal value. Furthermore, the agronomic properties of Adlay are now extensively studied but the focus in agricultural researches on this crop is more on yields. While there is much literature on the relationships between the nutrient availability in soils and associated yields, information on the amounts of macronutrients and micronutrients in the edible parts of many agricultural crops is limited.

An important component of the edible parts of crops, generally the seeds, is the quality of its chemical composition, which includes the amounts of essential elements (macro- and micro-elements) (Waters and Sankaran, 2011), and even the possible content of toxic elements. While the essentiality of both macro- and micro-elements cannot be repudiated for plant growth, some of these elements if present in the edible parts may also be toxic to animals and humans, at high concentrations (Wang *et al.,* 2008).

The propensity for plants to accumulate and translocate elements to edible parts depends to a large extent on soil and climatic factors, plant genotype, and agronomic management (McLaughlin *et al.,* 1999). However, quantitative data on micro- and macro-elements, and toxic element density in food crops grown on different types of soils are limited.

As an alternative and new crop, it is therefore, imperative and urgent to determine the chemical characteristics of Adlay, specifically the quantities of micro- and macro-elements, and toxic elements (lead and cadmium), in the grits and hull/testa, relative to the amounts of these elements and other physico-chemical properties of the soil where these plants are planted.

METHODOLOGY

Location of the Study

Soils and the grains of Adlay were collected from the farms in Kuya, Maramag, Bukidnon (Site 1), Northern Mindanao Agricultural Research Center (NOMIARC), Dalwangan, Malaybalay City, Bukidnon (Site 2), and Provincial Industrial Zone, Dicklum, Manolo Fortich, Bukidnon (Site 3).

The Adlay plantation in Site 3 was about one hectare and was within the Bukidnon Provincial Industrial Zone where the foreclosed and condemned tomato paste processing plant is located. This zone is now being used as the experimental station of the Provincial Agriculture Office of Bukidnon for some agricultural crops. During cultivation of Adlay in this site applications of lime and vermicast organic fertilizer were done. The soil in this site belongs to the Adtuyon clay series in order of Ultisols in Paleudults/Hapludults great group which may have evolved from volcanic lava or lahars composed of mixed basalt and andesite (Dejarme-Calalang and Colinet, 2014).

Site 2 was within the agricultural experimental station of NOMIARC. The Adlay plantation in this site was about one-half of a hectare and was surrounded with other agricultural crops developed and studied by NOMIARC. During cultivation of Adlay vermicast organic fertilizer was applied. The soil in this site also belongs to the Adtuyon clay series in order of Ultisols in Paleudults/Hapludults great group with parent material of volcanic lava or lahars composed of mixed basalt and andesite (Dejarme-Calalang and Colinet, 2014). On the other hand, the Adlay plantation in Site 1 was about two hectares and was a grassland before it was planted with Adlay. This site was surrounded with corn and sugarcane plantations and was cultivated with Adlay without an application of any fertilizer. The soil in this site belongs to the La Castellana clay series in order of Alfisols in Hapludalfs great group which may have evolved from igneous materials mainly basalt and andesite (Dejarme-Calalang and Colinet, 2014).

Collection and Preparation of Samples

The soils and the seeds of Adlay were collected from five randomly selected sub-sites (about 5m x 5m area) in each site. The soils were collected from 0-15cm using a soil auger. The soils from the five sub-sites, in each site, were composited. The seeds of Adlay from five sub-sites were collected by cutting the stalks of 8-10 plants using a knife. The seeds were then manually removed from the branches and were composited.

The collected soils from each site were homogenized, air-dried and quartered. A quarter of the air-dried soil from each site was pulverized using mortar and pestle and passed through a 0.5mm sieve. The sieved soil was oven-dried at 110^{0}C for 48 hours to ensure removal of water.

The collected seeds of Adlay from each site were thoroughly mixed and air-dried for two days. The dried seeds were quartered and one quarter was crushed using mortar and pestle. The crushed seeds were winnowed to separate the grits from hull and testa. The grits and the hull/testa were separately powdered using Wiley mill. The powdered grits and hull/testa were oven-dried at 75^{0}C for 48 hours to ensure the removal of water.

The soil chemical properties (pH, organic matter, and phosphorus (P)) were analyzed at the Soil and Plant Analytical Laboratory (SPAL) of the College of Agriculture of Central Mindanao University, Maramag, Bukidnon and the remaining soil parameters (potassium (K), nitrogen (N), EC and CEC) were analyzed in Unifrutti Philippines Incorporated (UPI) Biotechnology and Research Services Analytical Laboratory, Alanib, Lantapan, Bukidnon.

Phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), copper (Cu), boron (B), zinc (Zn), iron (Fe), sodium (Na), and cadmium (Cd) present in the grits and hull/testa of Adlay and in soils were analyzed at UPI Biotechnology and Research Analytical Laboratory, Alanib, Lantapan, Bukidnon while the analysis of lead (Pb) in the grits and hull/testa and in soil was done at Davao Analytical Laboratory Incorporated (DALINC), Davao City.

Methods of Analysis

The powdered and oven-dried samples of grits and hull/testa of Adlay were analyzed for K, Ca, Mg, Fe, Zn, Cu, Mn, Na, Cd, and Pb (Dry Ashing and Atomic Absorption Spectrometry (AAS- Varian AA240FS Fast Sequential Atomic Absorption Spectrometer)); B (Hot Water Extraction/Carmine Method), and for P (Vanadomolybdate Method).

The chemical properties of soil samples were analyzed for pH (1:2) (Mettler Toledo); EC (1:2) (Mettler Toledo); CEC (Ammonium Acetate Extraction and Kjeldahl Distillation); nitrogen (Kjeldahl Distillation); OM (Walkley-Black Method); B (Hot Water Extraction/Carmine method); P (Bray P_2-Murphy and Riley Method); K, Ca, Mg, Na, and Cd (Ammonium

Acetate Extraction/AAS-Varian AA240FS Fast Sequential Atomic Absorption Spectrometer); Fe, Zn, Mn and Cu (Diethylene triamine pentaacetic acid (DTPA) Extraction/AAS- Varian AA240FS Fast Sequential Atomic Absorption Spectrometer); for Pb (Dry ashing/AAS-Shimadzu AA6300 Atomic Absorption Spectrometer).

Statistical Analysis

The data points in this study were summarized using means. One-Way Analysis of Variance (ANOVA) was done to the values of chemical properties of soil and the amounts of essential and toxic elements in the grits and hull/testa of Adlay. Multiple comparisons using Tukey's Procedure at 5% and 1% level were also performed. The possible correlations between the soil properties and the grits and the hull/testa parameters for the Adlay were determined using Pearson r-correlation procedure.

RESULTS AND DISCUSSION

Soil Chemical Properties

The chemical properties of the soils (Table 1) from three different sites revealed positive correlations (Table 2) between pH and EC and between %OM and CEC. Negative correlations, however, were revealed between %OM and EC, between EC and CEC, and of pH with both %OM and CEC.

Different but appreciable amounts of macro- and micro-elements in the soils from the three different sites were revealed (Table 1) in the analyses.

The soils from Site 2 and Site 3 showed similar trend of the average amounts of macro-elements in the order of Ca>K>Mg>P while Site 1 showed that Ca>Mg>K>P. The amounts of Ca in the soils of Site 1 and 2 were within the very low rating (0-800 ppm) while that of Site 3 was within the medium level rating (2000-4000 ppm) for plant growth and development (Hazelton and Murphy, 2007). The amounts of Mg in the soils of Site 1 and Site 3 were within the medium level rating (60-300 ppm) while that of Site 2 which was less than 60 ppm belonged to the low level rating (Horneck *et al.,* 2011). The available amounts of P and K in the soils from the three sites which were all less than 20 ppm and 150 ppm respectively, belonged to the low level rating for plant growth and development (Horneck *et al.,* 2011).

Table 1. Comparison of means of the physico-chemical properties of the soils in Bukidnon grown with Adlay.

Physico-Chemical Properties	Values		
	Site 1 (Maramag)	Site 2 (Malaybalay)	Site 3 (Manolo Fortich)
pH	4.90^{b}	4.91^{b}	7.16^{a}
OM *(%)*	4.79^{a}	4.97^{a}	3.99^{b}
N *(%)*	0.16^{bc}	0.20^{a}	0.17^{ab}
EC($\mu S/cm$)	55.03^{c}	83.70^{b}	335.63^{a}
CEC(m*eq/100g)*	23.47^{b}	25.22^{a}	19.05^{c}
P	11.61^{b}	18.93^{a}	5.05^{c}
K	77.19^{b}	155.56^{a}	110.55^{a}
Ca	341.37^{c}	575.21^{b}	3953.87^{a}
Mg	137.37^{a}	56.26^{c}	80.02^{b}
Na	11.06^{b}	12.83^{a}	10.25^{c}
Fe	27.26^{a}	21.73^{b}	2.54^{c}
Zn	1.47^{a}	1.11^{b}	1.17^{b}
Cu	1.19^{b}	2.92^{a}	1.24^{b}
Mn	55.28^{a}	56.53^{a}	4.31^{b}
B	0.43^{b}	0.88^{a}	0.34^{b}
Cd	1.07^{b}	1.26^{ab}	1.47^{b}
Pb	1.06^{b}	1.28^{a}	nd

The values in the table for P to Pb are in ppm unit.
Mean values followed by the same letter superscript within row are not significantly different from each other at $p<0.05$.
nd means not detected

Table 2. Pearson r-correlation coefficients of the chemical properties of the soils in Bukidnon grown with Adlay.

Soil Properties	pH	OM	N	EC	CEC
pH	1				
OM	-0.733*	1			
N	-0.233	0.236	1		
EC	0.993**	-0.748*	-0.151	1	
CEC	-0.950**	0.729*	0.468	-0.920**	1

*Correlation is significant at 0.05 level
**Correlation is significant at 0.01 level

The average amounts of micro-elements in the soils from Site 1 generally followed the order of Mn>Fe>Na>Zn>Cu>B, Mn>Fe>Na>Cu>Zn>B for Site 2, and Na>Mn>Fe>Cu>Zn>B for Site 3. The Mn contents in the soils of Site 1 and Site 2 were very high relative to the sufficiency level (1-5 ppm) while that of Site 3 was within the sufficiency level (Horneck *et al.*, 2011). The amounts of Fe, Na and Zn in the soils from all sites were respectively, lower than the critical range (30-550 ppm) for Fe (Hamza, 2008), at very low level category (0-23 ppm) for Na, and above the desired level (0.2-0.6 ppm) for Zn (Hazelton and Murphy, 2007). The Cu content of the soils in each site were all above the critical range of 0.2-0.3 ppm (Horneck *et al.*, 2011). On the other hand, the amounts of B in the soil from Site 2 belonged to medium category (0.5-1 ppm) while those of Site 1 and Site 3 were within the low category (0.2-0.5 ppm) for plant nutrition (Horneck *et al.*, 2011).

The presence of Pb and Cd in the soils from the three sites grown with Adlay was also revealed in the analyses. The highest amount of Pb was observed in Site 2 followed by Site 1 and that of Site 3 was below the detection limit of the AAS used. For Cd, Site 3 showed the highest amount while the lowest amount was observed in Site 1. These Pb and Cd contents of the soils were all below the maximum (150 ppm for Pb and 3 ppm for Cd) allowable soil contaminant concentrations for land used for food production set by Environmental Protection Authority (EPA) (Hazelton and Murphy, 2007).

The presence and the variations in the amounts of each of the macro-elements, micro-elements, and the two toxic elements in the soils from the three sites could be attributed to the differences or variations in the natural and anthropogenic factors among sites. The textures of the soils from both Site 1 and Site 3 were analyzed as clay while that of Site 2 was sandy clay loam. Site 1 was a grassland before it was planted with Adlay and this site was surrounded with agricultural crops like corn and sugarcane. The soil of Site 2 was applied with vermicast fertilizers during cultivation and was within the experimental station of NOMIARC for agricultural crops. The soil of Site 3 was also applied with vermicast fertilizers in addition to lime during cultivation. This site was within the Provincial Industrial Zone of Bukidnon where the agricultural crops experimental station of the Bukidnon Provincial Agriculture Office and the foreclosed and condemned tomato paste processing plant are located.

Macro- and Micro-elements, Lead and Cadmium Contents in Grits of Adlay

The results for the analyses of the grits of Adlay from three different sites are shown in Table 3 while the Pearson r-correlation coefficients between some elements in grits and soil properties are shown in Table 4. The amounts of the four macro-elements analyzed in the grits showed similar trends, for all the three sites, in the order of K>P>Mg>Ca. The amounts of P and K in grits were all significantly different among sites. The difference in the amount of P in grits among sites could be attributed to the differences in the amounts of P in the soil as the Pearson r-correlation showed the amount of P in grits to be positively correlated with the amount of P in soils. On the other hand, the amount of K in grits showed positive correlation with the CEC of the soil and it could mean that higher CEC of the soil could have made the K in the soil more available for plant uptake (McKenzie *et al.*, 2004).

Table 3. Comparison of means of the macro-, micro- and toxic elements in the grits of Adlay among the three different sites in Bukidnon.

Element	Concentration		
	Site 1 (Maramag)	Site 2 (Malaybalay)	Site 3 (Manolo Fortich)
P	2136.66^{b}	2533.33^{a}	1566.67^{c}
K	2500.00^{b}	3166.66^{a}	1968.66^{c}
Ca	206.66^{b}	223.33^{b}	496.66^{a}
Mg	1073.33^{a}	1093.33^{a}	703.33^{b}
Na	98.65^{a}	99.00^{a}	83.40^{a}
Fe	224.13^{a}	65.63^{b}	76.83^{b}
Zn	20.38^{a}	17.47^{ab}	14.03^{b}
Cu	1.92^{b}	2.51^{a}	2.66^{a}
Mn	28.92^{a}	28.18^{a}	21.87^{b}
B	2.48^{a}	2.20^{a}	2.31^{a}
Cd	0.18^{a}	0.23^{a}	0.12^{a}
Pb	nd	nd	nd

Mean values followed by the same letter superscript within row are not significantly different from each other at $p<0.05$.
nd means not detected

Table 4. Pearson r-correlation coefficients between the elements in grits and hull/testa of Adlay and the soils properties.

Elements	Soil Properties	r-Coefficients
Grits		
P	P	0.96**
Ca	Ca	0.95**
K	CEC	0.92**
Mg	pH	-0.94**
Zn	pH	-0.78*
Mn	pH	-0.97**
	Mn	0.96**
Cu	Zn	-0.86**
Cd	CEC	0.75**
Hull/testa	P	0.68*
Fe	Zn	0.77*
Zn	Fe	0.75*
B	OM	-0.85**
Cd	Cd	0.87**
	Fe	-0.84**
	Mn	-0.70*

*Correlation is significant at 0.05 level
**Correlation is significant at 0.01 level

While the amounts of Mg in the grits from Site 1 and Site 2 showed no significant difference from each other, the amounts of Mg from these two sites were significantly higher than that of the grits from Site 3. As the Mg content in grits showed a significant negative correlation with the pH of the soil it could therefore mean that the pH of the soil in Site 3 which was slightly basic could have lessened the speciation of Mg for uptake and accumulation in Adlay. On the other hand, the acidic soils of Site 1 and Site 2 could have increased the speciation and availability of Mg in the soil for the accumulation of Adlay.

The amounts of Ca in grits from Site 1 and Site 2 showed no significant difference from each other but their amounts were significantly lower than that of Site 3. The Pearson r-correlation showed the amount of Ca in grits to be highly correlated with the amount of Ca in soil and it could mean that the higher the amount of Ca in the soil the higher the availability of Ca for plant uptake.

The amounts of six micro-elements analyzed in the grits of Adlay revealed similar trends for both Site 2 and Site 3 in the order of Na>Fe>Mn>Zn>Cu>B. However, Site 1 showed the trend in the order of Fe>Na>Mn>Zn>B>Cu. Only Fe, Zn, Mn, and Cu revealed significant differences in their amounts among sites. The differences in the amounts of Fe in the grits among sites could be attributed to the differences in the amount of Fe in the soils. The differences in the amounts of Zn in grits between Site 1 and Site 3 could be attributed to the differences in the pH of the soil of the two sites. The negative correlation observed between the Zn in grits and the pH of the soil may explain this difference. Parker *et al.* (1990) and Davis-Carter *et al.* (1993) both observed that higher pH caused the Zn in soil to be less available for uptake and accumulation in peanuts.

The differences in the amounts of Mn in grits from Sites 1 and 2 with that of Site 3 could be attributed to the differences in the amounts of Mn in the soil but great effect could be attributed to the pH of the soil. The Mn content in grits was positively correlated with the Mn of the soil but was negatively correlated with the pH. The lower pH of the soil could have increased the speciation of Mn in soil solution making it more available for plant uptake (Vega, 1992). On the other hand, the variations in the amounts of Cu in the grits of Sites 2 and 3 with that of Site 1 could be attributed to the antagonistic interactions between Cu and Zn in the soil. As negative correlation was observed between the Cu in grits and the amount of Zn in the soil, it may therefore mean that the Zn in soil could have depressed the absorption and accumulation of Cu (Hafeezl *et al.*, 2013) in Adlay.

Pb was not detected in the grits of Adlay. While the result revealed the presence of Cd in grits in three sites the amounts were not significantly different from each other. However, positive correlations were observed in the amount of Cd in the grits with both the CEC and amounts of P in the soils. Yu and Zhou (2009) explained that the available P in soil in the form of $H_2PO_4^{-1}$ may positively influence the plant-available Cd in soils through co-sorption as ion pairs.

Macro- and Micro-elements, Lead and Cadmium Contents in Hull/Testa of Adlay

The amounts of the elements analyzed in the hull/testa of Adlay are shown in Table 5 and the Pearson r-correlation coefficients between some elements in hull/testa and soil properties are shown in Table 4.

Table 5. Comparison of means of the macro-, micro-, and toxic elements in the hull/testa of Adlay among the three different sites in Bukidnon.

Element	Concentration		
	Site 1 (Maramag)	Site 2 (Malaybalay)	Site 3 (Manolo Fortich)
P	2163.33[a]	2656.67[a]	2670.00[a]
K	3533.33[a]	3676.67[a]	3830.00[a]
Ca	593.33[a]	626.67[a]	693.33[a]
Mg	1376.67[a]	1686.67[a]	1690.00[a]
Na	86.73[a]	99.22[a]	125.20[a]
Fe	84.85[b]	220.81[a]	168.63[ab]
Zn	22.79[b]	28.48[ab]	31.31[a]
Cu	3.79[a]	4.61[a]	5.45[a]
Mn	36.42[a]	39.48[a]	36.08[a]
B	5.40[b]	4.91[b]	11.53[a]
Cd	nd	0.16[a]	0.25[a]
Pb	nd	nd	nd

Mean values followed by the same letter superscript within row are not significantly different from each other at $p<0.05$.
nd means not detected

The amounts of macro-elements in hull/testa of Adlay showed the same trends in all sites in the order of K>P>Mg>Ca but the amount of each of these four macro-elements revealed no significant differences among sites. On the other hand, the amounts of the six micro-elements showed the same trend in the order of Fe>Na>Mn>Zn>B>Cu for both Sites 2 and 3 while Site 1 showed the amounts in the order of Na>Fe>Mn>Zn>B>Cu. No significant difference in the amounts of Na, Cu and Mn was observed among sites however, Fe, Zn, and B showed significant differences in their amounts among sites. The differences in the amounts of both Fe and Zn in hull/testa among sites could be attributed to the differences in the amounts of Zn and Fe in the soils, respectively. Negative correlations were observed between the amounts of Fe in hull/testa and Zn in soil and between the Zn in hull/testa and Fe in soil. These may mean that the Fe and Zn in soil had an antagonistic interaction relative to their absorption and accumulation in the hull/testa of Adlay. Hafeezl *et al.* (2013) also revealed in their review of the role of Zn in plant nutrition the antagonistic interaction between Fe and Zn in soil during uptake or absorption by plants. On the other hand, the differences in the amounts of B in the hull/testa among sites could be attributed to the differences in the amounts of organic matter in the soils.

Negative correlation was observed between B in hull/testa and OM in soil. This observation may mean that a higher amount of organic matter in soil could have lessened the availability of B in soil for plant uptake as B could have formed a complex with organic matter in the soil (Reichman, 2002).

Pb was not detected in the hull/testa of Adlay from all sites while Cd was detected only from Site 2 and Site 3. The amount of Cd in hull/testa showed positive correlation with Cd in soil and negative correlations with both Fe and Mn of the soils. Nazar *et al.* (2012) have shown that high amounts of Fe and Mn in soils could lower the Cd uptake of the plant.

Comparison of Macro- and Micro-elements, Lead and Cadmium Contents among the Soil, Grits and Hull/Testa of Adlay.

The amounts of the four macro-elements analyzed in the soil generally followed the order of Ca>K>Mg> P while the grits and hull/testa revealed the amounts of the four macro-elements in the same order of K>P>Mg>Ca. The higher amounts of K, P and Mg in both grits and hull/testa, relative to that of the soil could be accounted to the inherent or specific ability of Adlay to absorb and accumulate those elements from the soil. Welch (1995) explained that in deficiency and sufficiency situations, the activity of the free metal ion in the soil solution is low but plants could develop strategies to maximize the uptake of metals. Further, the plant has the ability to influence the solubility and speciation of metals in the rhizosphere by exuding chelators and manipulating the pH of the rhizosphere. Graminaceous monocots, of which Adlay is a member, could excrete chelates such as mugeneic and avenic acids. These chelates were found to associate with metals onto the rhizosphere providing a ready supply of metals for transport across the plant plasma membrane (Fan *et al.*, 1997).

The amounts of the macro-elements in both the grits and hull/testa in the order of K>P>Mg>Ca almost follow the typical, low-to-excess, amounts of macro-elements in plants tissues in the order of K (1.0-5.0%) > P (0.15-0.80%) > Ca (0.10-1.50%) ≥ Mg (0.10-1.0%) (McKenzie, 1998). However, the amount of Ca in both the grits and hull/testa of Adlay is lower relative to the typical amounts of Ca in many plants. This difference could be attributed to the specific anatomical, biochemical and/or physiological properties (Singh *et al.,* 2010) of Adlay towards Ca accumulation. These same factors may also be the cause for the differences in the accumulated amounts of the four macro-elements between the grits and hull/testa. The amounts of micro-elements in hull/testa in the order of

F>Na>Mn>Zn>B>Cu followed the trend of the typical, low-to-excess amounts of micro-elements in plant tissues in the order of Fe (15-500 ppm) > Mn (10-250 ppm) ≥ Zn (10-150 ppm) > B (3-75 ppm) > Cu (1.7-50 ppm) (McKenzie, 1998). The amounts of micro-elements in the grits in the order of Fe>Na>Mn>Zn>Cu>B showed a slight difference with the trend of the typical, low-to-excess amounts of micronutrients in plants as the Cu and B contents in the grits were slightly lower than that of the typical range in plants.

The average amount of Cd in the soils in Bukidnon grown with Adlay was found to be 1.270 ppm while that of Pb was found to be 0.715 ppm. Although Pb was present in the soil, no detectable amount of it was accumulated in both the grits and hull/testa. While Cd was present in both the grits and hull/testa, these amounts were lower than that of the soil. Fijałkowski *et al.* (2012) explained that a well- balanced and sufficient amount of macro- and micro-elements in the soil often results in less accumulation of heavy toxic metals in plants. Based on the Joint FAO/WHO Food Standards Programme-Codex Committee on Contaminants in Food, the amounts of Cd in grits and hull/testa were below 0.4 ppm, the maximum permitted level for Cd in cereals.

Comparison of Macro- and Micro-elements, Lead and Cadmium Contents among Adlay, Rice and Corn

The amounts of macro-, micro-elements, lead, and cadmium in grits of Adlay from the analyses of this study were compared with those in the grains of rice (*Oryza sativa* L.) and corn (*Zea mays* L.) from literatures (Table 6). The grits of Adlay showed higher amount of Ca compared to that of the reported amounts of Ca in both rice (white, long grain, raw and unenriched) and corn (white) grains by the United States Department of Agriculture National Nutrient Database (USDA-NND) (2014). The amounts of P, K, and Mg in the grits of Adlay were higher than that of the grains of rice but comparatively lower to that of corn.

The amounts of micro-elements in the grits of Adlay were also comparable with those of the grains of both rice and corn. The amount of Fe in the grits of Adlay was higher than that of rice and corn reported by the USDA-NND and that of the review of Teklic *et al.* (2013) on the metallic trace elements in cereal grains. The amount of Mn in Adlay was also higher than those of corn and rice of USDA-NND. This amount of Mn in Adlay was also higher than that of the corn in the review of Teklic *et al.* (2013) but was relatively lower than that of the rice. The amounts of Zn and Cu in the grits of Adlay were relatively higher than that of rice but were lower relative to that of the corn of USDA-NND. The review of Teklic *et al*. (2013) revealed higher amounts of Zn and Cu in both rice and corn than in the grits of Adlay but most of the rice and corn considered in their review were products of breeding for biofortification of micro-elements, Fe, Zn, Cu and Mn, as strategy to overcome micronutrient deficiency in cereals. The amount of Na in the grits of Adlay was lower than that of corn but was almost twice as high with that of the rice of USDA-NND. The amount of B in the grits of Adlay was almost the same with those of the five varieties of rice studied by Bhutto *et al.* (2013), but was lower with that of the corn studied by Wang *et al.* (2008).

Table 6. Comparison of range/average amounts of the macro-, micro- and toxic elements among the grains of rice (*Oryza sativa* L.), corn (*Zea mays* L.) and the grown Adlay (*Coix lacryma-jobi* L.) in Bukidnon.

Element	Concentration (ppm)		
	Rice	Corn	Adlay
P	1150.00[a]	2100.00[a]	2078.89
K	1150.00[a]	2870.00[a]	2544.44
Ca	280.00[a]	70.00[a]	308.89
Mg	250.00[a]	1270.00[a]	956.67
Na	50.00[a]	350.00[a]	93.68
Fe	22.00[b], 8.00[a]	28.40[b], 27.10[a]	122.20
Zn	26.50[b], 10.90[a]	24.70[b], 22.10[a]	17.29
Cu	7.20[b], 2.20[a]	3.50[b], 3.10[a]	2.37
Mn	29.30[b], 10.90[a]	7.00[b], 4.80[b]	26.26
B	1.88-2.81[c]	4.90[d]	2.33
Cd	0.05-0.28[e]	(i)0.08[f]; (ii)0.02[f]	0.18
Pb	0.20-1.50[g]	(i)0.67[f]; (ii)0.11[f]	nd

References for values : [a]USDA-NND; [b]Teklic *et al.* (2013); [c]Bhutto *et al.* (2013); [d]Wang *et al.* (2008);[e]Li *et al.* (2009); [f]Cortez and Ching (2014); [g]Solidum (2014)

(i) Dumpsite
(ii) Farmland
nd means not detected

The amount of Cd present in the grits of Adlay fall within the range of Cd present in the grains of rice grown on a differently fertilized soil studied by Li *et al.* (2009). This amount of Cd in the grits of Adlay however, was relatively higher than that of the grains of corn grown near a (i) dumpsite and from a (ii) farmland studied by Cortez and Ching (2014). The soils where the Adlay were grown contain high amounts of Cd relative to the amounts of Cd in the soils from where the rice of Li *et al.* (2009) and the corn of Cortez and Ching (2014) were grown. However, the comparison of the Cd accumulation factors of the three crops would suggest Adlay to be less Cd accumulator than rice and corn. The study done by Cortez and Ching (2014) on corn grown near a (i) dumpsite and from a (ii) farmland also revealed an accumulated amount of Pb in the grains of the corn. Solidum (2014) was able to quantify amounts of Pb from the grains of ten varieties of commercial rice in Metro Manila, Philippines. This study however, detected no amount of Pb in the grits of Adlay.

CONCLUSION

This study provides new and particular information on the chemical characteristics of Adlay (*Coix lacryma-jobi* L. Gulian variety) grown in Bukidnon, with respect to the essential elements (macro- and micro-elements) absorption *vis-à-vis* soil chemistry.

This study revealed that the amounts of P, Ca, K, Fe, Mn, and Cu in the grits of Adlay were differentiated by P, Ca, CEC, Fe, Mn, and Zn of the soil, respectively. The amounts of Mg, Zn, and Mn in grits were influenced by the pH of the soil. In hull/testa Fe was differentiated by the Zn in soil, the Zn by the Fe in soil, and B by %OM. The amounts of Pb and Cd in both grits and hull/testa were all below the maximum permitted level by FAO and WHO. The comparison of the amounts of macro-, and micro-elements relative with those of the two well-known and most important food crops, corn and rice, revealed Adlay to be a potential alternative source of these macro-, and micro-elements.

Most food crops are only analyzed for their food value (carbohydrates, lipids and proteins) neglecting their elemental composition which could be affected by the chemistry of the soil on which the crops are planted. This study on Adlay reveals the association between soil chemistry and crop elemental composition. Fortunately, results show that from the amounts of these elements in Adlay, planted in Bukidnon, it may well be a good alternative food crop for human and animal consumption.

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