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# Variability in Morpho-physiology, Tuber Yield and Starch Content of Several Arrowroot Populations in Garut District

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## ABSTRACT

Arrowroot (*Maranta arundinacea* L.) is an important starchy plant which has potential utilization for food, industry and medicine. The study was undertaken to assess the variability in morpho-physiological characters, tuber yield and starch content of 23 arrowroot populations in Garut District, West Java. The result showed some significant differences in morpho-physiological characteristics, tuber yield and starch content. Growth characteristics revealed that Cilawu population recorded the highest values for some characters: high, leaf number, above-growth biomass and tuber biomass. Cikajang population showed the highest tuber yield (210.6 g per plant) followed by Cilawu population (134 g per plant). Cikajang and Cilawu populations also provided the highest tuber biomass, 46.6 g and 60.0 g respectively. Cilawu population was a second population producing the highest starch content (26.1 %) after Cibatu population (27 %). The higher heritability coupled with genetic advance revealed for fresh tuber yield indicated that selection on basis of the character may be helpful to improve arrowroot yield. Most of the growth characteristics had not significant correlation indicating that the characteristics are not good indicator for selection. Cilawu, Cikajang and Cibatu populations have good potential to produce the high quality and quantity of tuber for arrowroot cultivation in Garut District.

Keywords: cultivation; genetic; growth; heritability; *Maranta arundinacea*

## INTRODUCTION

Arrowroot (*Maranta arundinacea* L.) is a perennial plant, harvested for its edible tubers, distributed on almost the whole tropical regions. The plant is a straight perennial herb with 1.0-1.5 m in high, superficial rooted with rhizomes growing into the soil. The best plant growth is in well drained on loamy or sandy soil and light shaded areas (Sujatha & Renuga, 2013). Some regions such as in the Caribbean islands, Southeast Asia, South America, and India, arrowroot was planted for food sources (Erdman, M. D. & Erdman, B. A., 1984; Odeku, 2013). The species also spread out on most of islands in Indonesia that is often found in community gardens as reserve of food for time of scarcity before main food harvest (Heyne, 1987). The cylindrical rhizomes (tubers) of arrowroot has high starch contents (Valencia, Moraes, Lourenço, Habitante, & do Amaral Sobra, 2014), well known as important medicinal plant used against diarrhea, urinary related diseases. The arrowroot starch also has a similar characteristic with cassava, potato, banana and achira starch (Valencia, Moraes, Lourenço, Habitante, & do Amaral Sobra, 2014; Shintu, Radhakrishnan, & Mohanan, 2015). At the present, arrowroot is a potential shading tolerant tuber crop for food, feed and medicinal herbs (Damat, 2012; Nishaa, Vishnupriya, Sasikumar, Christabel, & Gopalakrishnan, 2012; Shintu, Radhakrishnan, & Mohanan, 2015), which can be incorporated into the forest stand in the agro-forestry patterns, without disturbing forest as global facility to reduce $CO_2$ emission and other glass house gases.

In tuber crops, the number of roots which eventually form tubers as well as earliness of tuber bulking and maturity may depend on the genotype, assimilate supply, photoperiod and temperature. The process of tuber formation and maturity may also depend on soil water supply, soil fertility and soil temperature (Ikpi, Gebremeskel, Ezumah, & Ekpere, 1986). Variation study on the arrowroot from 4 populations (Kerala, Bihar, Madhya Pradesh & Shillong) in India showed that the populations were no significant difference tuber production, morphological and biochemical traits (Sujatha & Renuga, 2013). In other study, Hermansyah,

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Murniyanto, & Badami (2009), Djaafar, Sarjiman, & Pustaka (2010), and Suhartini & Hadiatmi (2011) reported that environmental factors such as soil fertility (nitrogen content) and annual rainfall affected tuber yield of arrowroot.

On the other hand, tuber yield and starch content have multi component characters greatly influenced by some agro-climate conditions (Sastra, 2003) and also affected by genetic systems. Distribution of genotype and morpho-physiological characteristics of arrowroot are not well documented, whereas the characteristics contribute to tuber yield and starch content. Genetic diversity within and among populations is important for improving the specific potential characters and reveals a substantial factor of adaptive abilities of populations; also, it is best indicated for the knowledge of extent of variation available within the species (Subramanian et al., 1992). Information of the variations is required for collection of planting materials to develop the high productivity of arrowroot. Identifying the component variations (heritable and non-heritable), genetic association and relationships among characters (Singh & Chaudhary, 1985; Kahrizi & Mohammadi, 2009; Maniee, Kahrizi, & Mohammadi, 2009) and also can help the breeder to find the superior arrowroot plant.

The purpose of the study was to assess the variation of morpho-physiological characteristics, tuber yield and starch content and association among morpho-physiological characteristics and among agro-climate variables of arrowroot in Garut District. According to Sukesi (2013), Garut District is a suitable region for tuber crops cultivations in West Java and also this is related to the history of Garut District and local name of arrowroot, known as garut, so arrowroot could be a potential and superior tuber crop in Garut District (Garut District Goverment, 2012). Although arrowroot is grown to a very large limited extent in Garut District, very little information has been gathered concerning this crop's morphological traits, tuber yield and starch content.

## MATERIALS AND METHODS

### Samples Collection

Arrowroot exploration activities were conducted in Garut District, West Java Province from January – September 2014. Snowball samplings through direct survey and observation based on information obtained from local people were carried out to find the arrowroot populations. The exploration activity was inventoried and documented 23 populations of arrowroot. Site, habitat information, and cultivation status were recorded including its latitude-longitude, light intensity, temperature, and air humidity. Descriptions of the 23 sites are presented in Table 1. The samples of soil were dug up from 20 cm depth taken from each plant sample. The soil samples were bulked for each population to obtain the composite soil sample. Soil texture, pH, nutrients content, base saturation and cation exchange capacity were analyzed at Soil Laboratory, Faculty of Agriculture, Jenderal Sudirman University.

### Morpho-physiological Data

The data of 5 plants were recorded for morphological and physiological characteristics including total height, leaf number, leaf area, stomatal density, stomatal width, stomatal length, chlorophyll A, chlorophyll B, total chlorophyll, tuber production per plant, tuber length, tuber diameter, tuber biomass, harvest index and starch content, recorded at the end of 8 months. Stomatal density was observed by a nail polish impression of the abaxial surface of the first fully developed leaf harvested at the end of the treatments and measured under a light microscope in three random fields per leaf at ×40 magnification. The concentrations of chlorophyll were measured from a leaf at the second pair from the apices (Lichtenthaler, 1987) using a spectrophotometer (UV-1201, Shimadzu Corporation, Japan). For biomass measurements, all plants were harvested and divided into roots, stems, leaves and tuber. Roots, stems, leaves and tuber were dried separately in a drying oven at 70 °C for 48 h and weighed to ±0.0001 g. Leaves and stems were aggregated and are subsequently referred to as above-ground biomass. Total biomass was obtained from counting up of above-ground, root, and tuber biomass.

### Tuber Yield and Starch Content

Harvesting the rhizomes was carried out on maturity arrowroot plants (10-11 months after planting) indicated by wilting, yellowing and drying up of leaves. Five plants were randomly selected per site and the tubers were harvested manually and carefully to avoid damaging the tubers. The weight, length, diameter, biomass and harvest index of the tubers were measured per plant. Before starch extraction, the tuber was peeled and cleaned by distilled water. The method for starch extraction was conducted according to the Nelson-Somogyi method (Sudarmadji, Haryono, & Suhardi, 1997).

**Table 1.** Background information of the 23 populations

| Populations | Latitude (S) | Longitude (E) | Altitude (m asl) | Light intensity (%) | Temperature (°C) | Relative humidity (%) | Cultivation status |
|---|---|---|---|---|---|---|---|
| Babakan Cau (BBC) | 7°06'01.5 | 107°59'43.3 | 653 | 56.35 | 32 | 62 | W |
| Banjarwangi (BJW) | 7°24'37.2 | 107°52'55.5 | 921 | 21.51 | 28 | 48 | W |
| Binong (BIN) | 7°33'12.4 | 107°40'13.9 | 346 | 40.41 | 30 | 50 | W |
| Cangkuang (CKG) | 7°06'14.5 | 107°54'23.3 | 725 | 21.34 | 29 | 48 | W |
| Cibatu (CBT) | 7°05'07.5 | 107°58'50.9 | 605 | 30.56 | 34 | 50 | C |
| Cikajang (CKJ) | 7°23'22.2 | 107°49'48.3 | 1351 | 43.62 | 25 | 75 | C |
| Cikelet (CKL) | 7°36'55.9 | 107°39'49.4 | 6 | 26.28 | 36 | 40 | C |
| Cikondang (CKD) | 7°24'40.0 | 107°52'57.0 | 946 | 27.37 | 28 | 60 | W |
| Cilawu (CLW) | 7°17'01.0 | 107°54'55.6 | 1009 | 56.05 | 30 | 61 | C |
| Cisandaan (CSD) | 7°23'48.8 | 107°42'59.4 | 998 | 60.17 | 28 | 52 | W |
| Cisompet (CSP) | 7°33'27.3 | 107°47'26.4 | 322 | 34.24 | 30 | 58 | W |
| Depok (DPK) | 7 35'45.5 | 107°46'19.4 | 215 | 21.43 | 29 | 72 | W |
| Depok. Lebak (DLB) | 7°36'47.5 | 107°45'51.5 | 180 | 31.24 | 30 | 70 | W |
| Gunung Sulah (GNS) | 7°36'20.1 | 107°39'10.0 | 42 | 25.70 | 28 | 52 | W |
| Kampung Jati (KPJ) | 7°06'26.4 | 107°54'36.7 | 730 | 24.27 | 30 | 40 | W |
| Limbangan (LBG) | 7°01'15.7 | 108°00'44.9 | 572 | 30.60 | 36 | 45 | W |
| Munjul (MJL) | 7°14'35.6 | 107°53'20.4 | 837 | 21.34 | 29 | 48 | C |
| Neglasari (NGS) | 7°31'40.8 | 107°48'24.9 | 688 | 33.72 | 27 | 70 | W |
| Pamulihan (PML) | 7°15'56.5 | 107°46'55.6 | 895 | 26.24 | 29 | 49 | C |
| Pasir Gambir (PSG) | 7°34'07.2 | 107°40'15.6 | 264 | 26.65 | 31 | 49 | W |
| Sanding (SDI) | 7°33'43.6 | 107°40'21.6 | 262 | 27.59 | 30 | 50 | W |
| Sodong (SDO) | 7°33'33.4 | 107°40'22.3 | 262 | 46.31 | 31 | 44 | C |
| Sukatani (SKT) | 7°20'29.7 | 107°47'00.7 | 1283 | 16.54 | 27 | 40 | C |

Remarks: W = wild population, C = cultivated population

**Statistical Analysis**

A complete randomized design using SPSS (version 21) was used for analysis of variance and Duncan multiple range test to determine the differences of morpho-physiological characteristics, tuber yield and starch content among populations. Simple correlations (Pearson) at 5 % level of significance were calculated for morpho-physiological characteristics, tuber yield and starch content with agro-climate factors (altitude, temperature, relative humidity, plant spacing, cultivation status, and soil fertility).

Genotypic (GV), phenotypic (PV), environmental variances (EV), phenotypic (PVC), genotypic (GVC) and environmental coefficients of variation (ECV) were calculated using the following equations according to Burton (1951).

$GV = (Mt – Me)/r$; $PV = GV + Me$; $EV = Me$

$PCV\% = \sqrt{PV}/x \times 100$; $GCV\% = \sqrt{GV}/x \times 100$;

$ECV\% = \sqrt{EV}/x \times 100$

where: Mt = mean square for treatments, Me = mean error variance, and r = number of replicates, x = population mean for each trait.

Heritability in broad sense ($H^2B$) is the ratio of genetic variance to the total phenotypic variance (Allard, 1999). Genetic advance (GA) is the expected increase in the magnitude of a particular character when a selection pressure of chosen intensity (i) is applied.

$GA = GV/ PV \times i \times \sqrt{PV}$

where: i = selection intensity (2.06)

Genetic gain (GG) was calculated in percentage of mean using the formula according to Johnson, Robinson, & Comstock (1955). Bi-plot analysis was used to identify the performance and to cluster the arrowroot populations based on plant height, fresh tuber yield, tuber biomass, and starch content using SPSS (v21) for categorical principle component analysis.

## RESULTS AND DISCUSSION

### Morpho-physiological Traits, Tuber Yield and Starch Content

Analysis of variance showed presence of considerable variability among all arrowroot populations which was highly significant, except for tuber length (Table 2). The significant differences for most of the morpho-physiological characteristics, tuber yield and starch content indicated the existence of genetic variability among populations. Growth parameters indicated that the Cilawu population showed highest values for seven characters: high growth, number of leaf, above growth biomass (leaf and stem biomass), and tuber biomass. On the other hand, Babakan Cau population showed the lowest growth performance for seven characteristics: high growth, chlorophyll A, chlorophyll B, total chlorophyll, above growth biomass, root biomass and tuber biomass.

Variability studies for fresh tuber yield revealed that Cikajang population (210.6 g per plant) recorded high values followed by Cilawu population (134 g per plant). Cilawu population was a second population producing the highest starch content (26.1 %) after Cibatu population (27 %). On the other hand, Babakan Cau population followed by Limbangan, Banjarwangi, Neglasari, and Depok populations, exhibited lowest for tuber yield, while for starch content, Sanding population has the lowest content (Fig. 1). Other research reported the arrowroot starch content such as Sujatha & Renuga (2013) in Kanyakumari district of Tamil Nadu, India (17.20-18.86 %), Valencia, Moraes, Lourenço, Habitante, & do Amaral Sobra (2014) in Palmira, Colombia (17.2-18.9 %), and Faridah, Fardiaz, Andarwulan, & Sunarti (2014) in Bogor, Indonesia (15.69-20.96 %). Some populations in this research showed higher starch content than above references with the starch content of more than 25 %, such as Cibatu and Cilawu populations.

Morpho-physiological, tuber yield and starch content characters are interdependent, and all parameters are controlled by genetic and environmental factors. This suggests a combined control of genotype and environmental, such us climate and soil. Environmental factors may cause variation in plant characteristics. Plants required optimum environmental conditions to grow and produce maximum tuber yields *viz.* soil type and contents, water availability, altitude, climate, air temperature, humidity, light intensity, etc. (Sitompul & Guritno, 1995). Same plant species will show various morphology if environmental factor is more dominant in affecting plant than of the genetic factors and vice versa (Suranto, 1991).

**Table 2.** Variability estimates for morpho-physiological characteristics, tuber yield and starch content

| Parameters | Mean | Standard deviation | Critical differences |
|---|---|---|---|
| Plant height (cm) | 57.7 | 14.1 | 4.09** |
| Number of leaf | 4.3 | 0.5 | 7.65** |
| Leaf area ($cm^2$) | 921 | 221 | 4.71** |
| Stomata density (number per $mm^2$) | 24.7 | 5.4 | 3.55** |
| Stomatal length (μm) | 5.60 | 0.45 | 3.83** |
| Stomatal width (μm) | 2.37 | 0.31 | 2.58** |
| Chlorophyll A | 2.10 | 0.45 | 4.81** |
| Chlorophyll B | 0.58 | 0.18 | 6.59** |
| Total Chlorophyll | 2.65 | 0.64 | 5.37** |
| Above-growth biomass (g) | 9.63 | 1.11 | 1.91** |
| Root biomass (g) | 2.11 | 0.26 | 2.29** |
| Tuber biomass (g) | 19.4 | 10.8 | 4.95** |
| Fresh tuber yield (g) | 56.5 | 27.6 | 10.62** |
| Tuber length (cm) | 14.3 | 5.0 | 1.02ns |
| Tuber diameter (mm) | 19.1 | 4.2 | 2.00** |
| Tuber water content (%) | 65.5 | 13.8 | 7.34** |
| Harvest index | 0.58 | 0.20 | 2.35** |
| Starch content (%) | 18.9 | 3.9 | 6.32** |

Remarks: **= very significant at 99 % confident level, ns= not significant at 95 % confident level

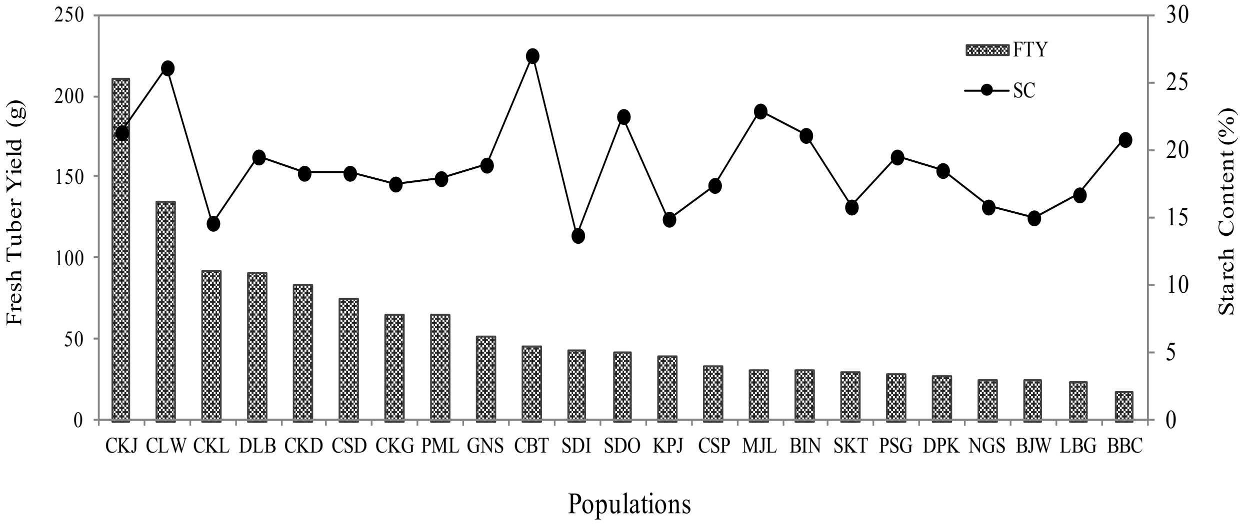


**Fig. 1.** Fresh tuber yield and starch content of 23 populations of arrowroot

**Variance, Coefficient of Variability**

In present investigation, phenotypic and genotypic coefficient of variations are the highest for fresh tuber production (12.89 and 13.54, respectively) and tuber biomass (12.10 and 13.54, respectively), while the maximum environmental coefficient of variation was associated with aboveground biomass (8.65). The lowest phenotypic and genotypic coefficient of variations was identified on tuber length, and the highest environmental coefficient of variation was recorded for stomatal length. Genotypic coefficient of variation for all morpho-physiological characteristics, tuber yield and starch content were found higher than environmental coefficient of variations and only two characters (tuber length and root biomass) were more influenced by environmental variations (Table 3). Similar trend was obtained in growth, physiological and biochemical parameters of *Pinus wallichiana* (Rawat & Bakshi, 2011) and *Anthocephalus cadamba* (Sudrajat, 2016). In this study, the most phenotypic and genotypic coefficients of variations was close to each other indicating that the genotypic components had higher contributor to the total variance than environment factors. Although the research location range was relatively narrow, the magnitude variation was observed almost in all characters. This indicates that variation in characteristics of arrowroot also occures in a narrow range and specifies the good scope in improvement on this species.

Higher heritability was reported for fresh tuber production per plant (FTP, 0.90) followed by tuber water content (TWC, 0.86), number of leaf (NL, 0.86), chlorophyll B (CLB, 0.84), and starch content (SC, 0.84) while the lower heritability was revealed by root biomass (0.47) followed by tuber length (0.02). Genetic gain ranged between 0.18 % (for tuber length) and 25.27 % (for fresh tuber yield). Some parameters such as number of leaf, chlorophyll B, total chlorophyll, tuber water content, and starch content revealed the high heritability values (>0.80). Heritability estimation can be used as a gross indicator for selection of one or more characteristics (Namkoong, Synder, & Stonecypher, 1966; Sudrajat, 2016). Although the parameters had good values of heritability, but for genotypic coefficient variation and genetic gain, the parameters had the lower values (Table 3). The lower values of genotypic coefficient variation and genetic gain indicated that the existence of non-additive genetic effects is higher than additive genetic effects. The total phenotypic variance (Vp) of each characteristic separated into a heritable (Vg) can be used to select for superior characters.

Heritability values along with genetic gain which is more essential than the heritability along to measure the resultant effect for selecting the best genotype. High heritability values associated with high genetic gain were revealed by fresh tuber yield. Conversely, high heritability values associated with low genetic gain were showed by number of leaf, chlorophyll B, total chlorophyll, tuber water content and starch content. This result indicated that non-additive genetic was more affected than additive components. Higher heritability, genetic gain and significant correlation indicated that selection on basis of these morpho-physiological characters may be helpful to improve arrowroot yield (Ali et al., 2014).

**Correlation Matrix and Population Grouping**

Simple correlation coefficient is a useful method to study the interrelationships among growth, tuber yield and starch content characters. Correlation matrix among morphological characteristics (Table 4) showed significant correlation among growth characteristics with other important characters like plant height which is correlated with above-ground biomass (0.79) and root biomass (0.63). Number of leaf is positively correlated with leaf area (0.65) and root biomass (0.63). A negative correlation of leaf area also occurred with tuber diameter (-0.48). Significant correlation of stomatal density occurred with tuber water content (0.73). A strong correlation was observed among chlorophyll and among tuber morphological characteristics revealing thus that these traits were independent and genetically controlled (Rawat & Bakshi, 2011). Other positive correlations were showed by fresh tuber yield per plant with tuber diameter (0.68) and tuber biomass (0.79); harvest index with tuber diameter (0.57) and tuber biomass (0.64); and root biomass with starch content (0.48). In some studies, tuber yield and starch content were complex characters associated with some growth traits (Zemba, Wuyep, Adebayo, & Jahknwa, 2013), but this research result showed that most of the growth traits had no significant correlation. This result indicated that the growth characteristics were not a good indicator for selecting the higher tuber production and starch content.

**Table 3.** Genotypic variance (GV), phenotypic variance (PV), environment variance (EC), genotypic coefficient of variability (GCV), phenotypic coefficient of variability (PCV), environment coefficient of variability (ECV), heritability (H2B) and genetic advance in percentage of mean (GG) for different characters of 23 populations of arrowroot

| Parameters | GV | PV | EV | GCV | PCV | ECV | H2B | GG (%) |
|---|---|---|---|---|---|---|---|---|
| H | 3.0817 | 4.0776 | 0.9959 | 3.0382 | 3.4982 | 1.7271 | 0.75 | 5.44 |
| NL | 0.0554 | 0.0637 | 0.0083 | 4.0653 | 4.3602 | 1.5763 | 0.86 | 7.80 |
| LA | 3002.11 | 3810.88 | 808.77 | 5.9427 | 6.6955 | 3.0845 | 0.78 | 10.86 |
| SD | 0.4191 | 0.5835 | 0.1643 | 2.6191 | 3.0901 | 1.6399 | 0.71 | 4.57 |
| SL | 0.0030 | 0.0040 | 0.0010 | 0.9820 | 1.1408 | 0.5807 | 0.74 | 1.74 |
| SW | 0.0010 | 0.0016 | 0.0006 | 0.9788 | 1.2500 | 0.7775 | 0.61 | 1.57 |
| CLA | 0.0036 | 0.0046 | 0.0009 | 2.8857 | 3.2419 | 1.4775 | 0.79 | 5.29 |
| CLB | 0.0006 | 0.0008 | 0.0001 | 4.5268 | 4.9146 | 1.9135 | 0.84 | 8.58 |
| TCL | 0.0076 | 0.0093 | 0.0017 | 3.2953 | 3.6528 | 1.5759 | 0.81 | 6.12 |
| FTY | 53.1803 | 58.7076 | 5.5273 | 12.8911 | 13.5444 | 4.1559 | 0.90 | 25.27 |
| TL | 0.0065 | 0.2594 | 0.2529 | 0.5630 | 0.3557 | 3.5119 | 0.02 | 0.18 |
| TD | 0.1361 | 0.2719 | 0.1358 | 1.9315 | 2.7302 | 1.9296 | 0.50 | 2.81 |
| TWC | 4.0049 | 4.6360 | 0.6311 | 3.0548 | 3.2867 | 1.2127 | 0.86 | 5.84 |
| TB | 5.5532 | 6.9558 | 1.4025 | 12.1034 | 13.5459 | 6.0826 | 0.79 | 22.27 |
| ABG | 0.0431 | 0.0765 | 0.0333 | 9.8444 | 13.1098 | 8.6576 | 0.56 | 15.22 |
| RB | 0.5981 | 1.2548 | 0.6566 | 8.0311 | 11.6322 | 8.4148 | 0.47 | 11.42 |
| HI | 0.0004 | 0.0006 | 0.0002 | 3.4371 | 4.5303 | 2.9512 | 0.57 | 5.37 |
| SC | 0.3072 | 0.3649 | 0.0576 | 2.9298 | 3.1929 | 1.2694 | 0.84 | 5.53 |

Remarks: H = plant height, NL = number of leaf, LA = leaf area, SD = stomatal density, SL = stomatal length, SW = stomatal width, CLA = chlorophyll A, CLB = chlorophyll B, TCL = total chlorophyll, AGB = above growth biomass, RB = root biomass, TB = tuber biomass, FTY = fresh tuber yield per plant, TL = tuber length, TD = tuber diameter, TWC = tuber water content, HI = harvest index, SC = starch content

**Table 4.** Coefficient of simple correlation (Pearson) among morpho-physiological characters, tuber yield and starch content of arrowroot

| | H | NL | LA | SD | SL | SW | CLA | CLB | TCL | FTP | TL | TD | TWC | TB | AGB | RB | HI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NL | 0.38 | | | | | | | | | | | | | | | | |
| LA | 0.12 | 0.65** | | | | | | | | | | | | | | | |
| SD | -0.23 | -0.38 | 0.01 | | | | | | | | | | | | | | |
| SL | -0.04 | -0.06 | 0.17 | 0.36 | | | | | | | | | | | | | |
| SW | -0.04 | -0.19 | -0.07 | 0.41 | -0.01 | | | | | | | | | | | | |
| CLA | -0.03 | 0.01 | -0.24 | -0.31 | -0.33 | -0.08 | | | | | | | | | | | |
| CLB | 0.01 | 0.01 | -0.18 | -0.26 | -0.36 | -0.09 | 0.98** | | | | | | | | | | |
| TCL | -0.02 | -0.14 | -0.38 | -0.25 | -0.30 | -0.14 | 0.96** | 0.95** | | | | | | | | | |
| FTP | 0.31 | 0.10 | -0.14 | 0.28 | -0.09 | -0.06 | 0.28 | 0.28 | 0.32 | | | | | | | | |
| TL | -0.19 | 0.18 | 0.30 | 0.31 | 0.17 | -0.20 | -0.08 | -0.03 | -0.07 | 0.38 | | | | | | | |
| TD | -0.17 | -0.21 | -0.48* | 0.31 | 0.16 | 0.04 | 0.19 | 0.10 | 0.28 | 0.68** | 0.46 | | | | | | |
| TWC | -0.28 | -0.36 | -0.01 | 0.73** | 0.11 | 0.39 | 0.17 | 0.22 | 0.15 | 0.16 | 0.18 | 0.12 | | | | | |
| TB | 0.42 | 0.35 | -0.07 | -0.15 | -0.13 | -0.25 | 0.10 | 0.08 | 0.15 | 0.79** | 0.26 | 0.54* | -0.44 | | | | |
| AGB | 0.79** | 0.35 | 0.20 | 0.15 | -0.13 | -0.15 | -0.10 | 0.01 | -0.10 | 0.33 | 0.17 | -0.02 | 0.16 | 0.26 | | | |
| RB | 0.63** | 0.63** | 0.45 | -0.22 | 0.01 | 0.04 | 0.19 | 0.21 | 0.06 | 0.29 | 0.06 | -0.18 | -0.09 | 0.28 | -0.46 | | |
| HI | -0.26 | -0.07 | -0.23 | -0.11 | -0.03 | -0.39 | 0.09 | 0.01 | 0.19 | 0.41 | 0.23 | 0.57* | -0.46 | 0.64** | 0.24 | -0.33 | |
| SC | 0.40 | 0.44 | 0.38 | -0.24 | -0.17 | -0.39 | -0.01 | 0.05 | 0.01 | 0.23 | 0.27 | -0.23 | -0.36 | 0.40 | 0.44 | 0.48* | 0.13 |

Remarks: See Table 3 for parameter information

**Table 5.** Simple correlation coefficients between seed characteristics and geographic variation

| | H | NL | LA | SD | SL | SW | CLA | CLB | TCL | AGB | RB | TB | FTY | TL | TD | TWC | HI | SC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alt | 0.35 | 0.12 | -0.33 | -0.22 | -0.36 | -0.12 | 0.43 | 0.43 | 0.48* | 0.22 | 0.28 | 0.30 | 0.43 | -0.18 | 0.16 | 0.07 | -0.03 | 0.20 |
| Tem | -0.35 | -0.19 | -0.10 | -0.29 | 0.01 | 0.00 | 0.01 | -0.03 | 0.01 | -0.33 | -0.32 | -0.03 | -0.29 | 0.08 | 0.06 | -0.35 | 0.29 | -0.15 |
| RH | 0.16 | 0.39 | 0.48* | 0.23 | -0.20 | 0.16 | 0.07 | 0.08 | -0.04 | 0.36 | 0.18 | 0.26 | 0.43 | -0.04 | -0.11 | 0.25 | -0.00 | 0.23 |
| LI | 0.42 | 0.22 | 0.32 | -0.12 | 0.08 | -0.14 | 0.09 | 0.11 | 0.16 | 0.37 | 0.17 | 0.52* | 0.35 | 0.03 | -0.06 | -0.32 | 0.30 | 0.65** |
| PS | 0.25 | 0.42 | 0.26 | 0.03 | -0.03 | 0.03 | -0.31 | -0.29 | -0.26 | 0.14 | 0.43 | 0.70** | 0.43 | 0.29 | 0.25 | -0.38 | 0.38 | 0.45 |
| CS | 0.24 | 0.12 | -0.25 | -0.36 | -0.30 | -0.20 | 0.52* | 0.51* | 0.57* | 0.34 | 0.02 | 0.41 | 0.47* | 0.32 | 0.33 | -0.22 | 0.27 | 0.40 |
| Sand | 0.11 | -0.36 | -0.36 | 0.09 | -0.20 | 0.17 | -0.14 | -0.15 | -0.06 | 0.09 | 0.03 | 0.14 | 0.27 | 0.20 | 0.35 | 0.02 | 0.08 | 0.13 |
| Dust | 0.19 | -0.01 | 0.15 | 0.19 | 0.32 | 0.25 | 0.12 | 0.14 | 0.05 | 0.19 | -0.01 | -0.45 | -0.27 | -0.32 | -0.34 | 0.34 | -0.50* | -0.36 |
| Clay | -0.25 | 0.43 | 0.30 | -0.23 | 0.01 | -0.36 | 0.08 | 0.08 | 0.04 | -0.24 | -0.02 | 0.16 | -0.12 | -0.01 | -0.16 | -0.27 | 0.26 | 0.09 |
| pH | -0.03 | -0.35 | -0.36 | -0.12 | -0.08 | -0.00 | -0.22 | -0.26 | -0.17 | -.052 | -0.20 | 0.07 | 0.01 | -0.08 | 0.09 | -0.22 | 0.14 | 0.24 |
| C | 0.43 | 0.04 | -0.31 | -0.42 | -0.43 | -0.29 | 0.40 | 0.47 | 0.37 | 0.26 | -0.07 | 0.40 | 0.37 | -0.34 | 0.06 | -0.28 | 0.30 | 0.26 |
| N | 0.55* | 0.05 | -0.36 | -0.31 | -0.43 | -0.15 | 0.36 | 0.35 | 0.43 | 0.32 | 0.16 | 0.34 | 0.38 | -0.34 | 0.10 | -0.17 | 0.08 | 0.15 |
| CN | -0.51* | -0.02 | 0.20 | -0.05 | 0.32 | -0.06 | 0.12 | 0.07 | 0.05 | -0.21 | -0.57 | -0.12 | -0.25 | 0.22 | 0.02 | -0.08 | 0.29 | -0.12 |
| P | 0.42 | -0.20 | 0.15 | 0.18 | 0.24 | 0.15 | -0.47 | -0.41 | -0.42 | 0.10 | 0.38 | -0.18 | -0.16 | 0.00 | -0.29 | 0.08 | -0.43 | -0.08 |
| Ca | -0.02 | -0.46 | -0.35 | 0.18 | -0.17 | 0.43 | -0.19 | -0.18 | -0.13 | -0.15 | 0.16 | -0.16 | -0.05 | -0.28 | 0.06 | 0.16 | -0.20 | -0.15 |
| Mg | -0.10 | -0.25 | -0.29 | 0.09 | -0.20 | 0.23 | -0.09 | -0.10 | -0.05 | -0.16 | 0.16 | 0.01 | 0.12 | -0.20 | 0.21 | 0.10 | -0.01 | -0.15 |
| K | -0.18 | -0.37 | -0.05 | 0.37 | 0.09 | 0.59* | -0.29 | -0.26 | -0.23 | -0.27 | 0.08 | -0.11 | -0.13 | 0.09 | 0.16 | 0.11 | -0.01 | -0.26 |
| Na | 0.05 | 0.26 | 0.40 | -0.04 | 0.25 | 0.01 | -0.08 | -0.03 | -0.11 | 0.00 | 0.13 | -0.06 | -0.28 | 0.03 | -0.31 | -0.11 | -0.13 | 0.03 |
| CEC | -0.09 | 0.49* | -0.22 | 0.40 | -0.08 | 0.42 | 0.08 | 0.19 | 0.16 | -0.23 | 0.38 | -0.42 | -0.15 | -0.01 | -0.04 | 0.36 | -0.49* | -0.26 |
| BS | -0.02 | -0.24 | -0.35 | -0.05 | -0.28 | 0.15 | -0.17 | -0.21 | -0.13 | -0.12 | 0.04 | 0.16 | 0.14 | -0.19 | 0.22 | -0.13 | 0.14 | -0.01 |

Remarks: Alt = altitude, Tem = temperature, RH = relative humidity, LI = light intensity, PS = plant spacing, CS = cultivation status, Sand = soil texture, Dust = soil texture, Clay = soil texture, pH = soil acidity, C = carbon, N = nitrogen, CN = ratio of carbon nitrogen, P = phosphor, Ca = calcium, Mg = magnesium, K = potassium, Na = natrium, CEC = capacity of cation exchange, BS = base saturation. See Table 3 for plant parameter information

Morpho-physiological characterization data availability in the relation with different agro-climate of arrowroot is still very limited. A positive correlation between altitude and total chlorophyll (0.48) suggested that total chlorophyll increased within higher altitude. Significant correlation was also found between relative humidity and leaf area (0.48) depicted that sites which had a relatively higher humidity tended to show greater leaf area. Light intensity was correlated with tuber biomass (0.52) and starch content (0.65) (Table 5). In the tree stand shaded condition, active sun light for photosynthesis process (wave length 400-700 nm) decreases influencing tuber development such as biomass and starch content. Similar result reported by Djukri (2006) that stated tuber biomass had a correlation with shading condition or light intensity. Plant spacing was also significantly correlated with tuber biomass (0.70) (Table 5). This revealed the larger space among arrowroot plant, the higher biomass in the tuber. Cultivation status (cultivated or wild crop) was correlated with chlorophyll content and fresh tuber yield. Chlorophyll was utilized as the light-trapping and energy transferring chromophore in photosynthetic plants (Anjum et al., 2011). Cultivated plants tended to have higher chlorophyll content and tuber yield than wild plants. The decrease of chlorophyll contents in hard shaded plant is considered a main cause of decrease of photosynthesis (Lambers, Stuart Chapin III, & Pons, 1998). Low chlorophyll concentrations directly affected to limit the photosynthetic potential and hence primary growth and production in storage tissue such as tuber (Zamski & Schaffer, 1996) caused a decrease of fresh tuber yield (Sastra, 2002).

Most of soil texture variables, except dust content did not show any significant correlation with morphological, tuber yield and starch content of arrowroot. Dust content showed positive correlation (0.422) with harvest index while other parameters revealed a non-significant correlation. Plant height was positive correlated with plant height (0.55) and negative correlated with ratio carbon-nitrogen (-0.51). Nitrogen (N) is typically the most limiting factor for plant growth and crop yield. Deficiency of nitrogen will decrease tuber yield by affecting the tuber production (Vaezzadeh & Naderidarbaghshahi, 2012). Significant correlation was also observed between potassium (K) and stomatal width (0.59). Potassium was recognized as a role in the opening of stomata aperture pores (Talbott & Zeiger, 1996). Other significant correlation was observed between cation exchange capacity and number of leaf, tuber water content and harvest index.

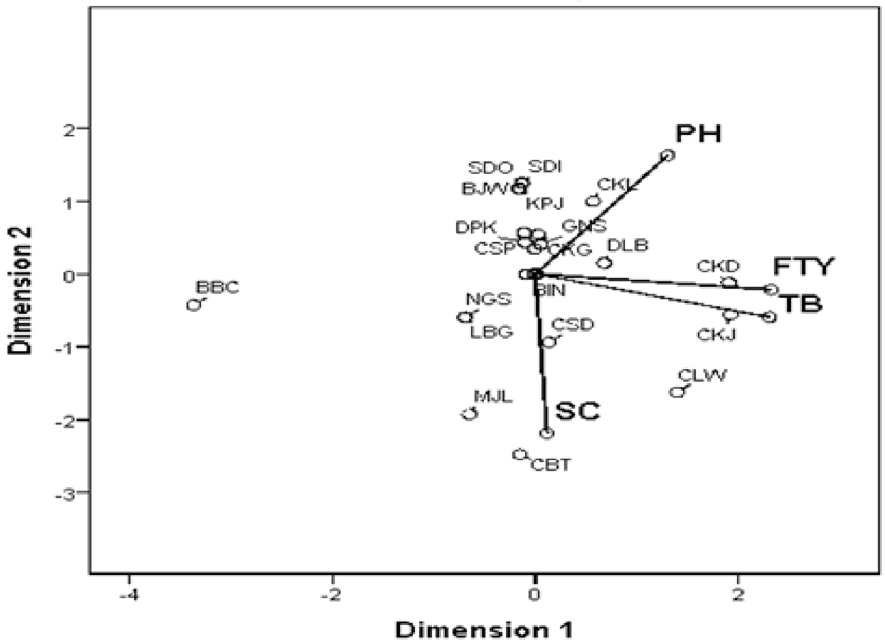


**Fig. 2.** Biplot of 23 arrowroot populations based on plant height (PH), fresh tuber yield (FTY), tuber biomass (TB), and starch content (SC)

Tuber yield, starch content and tuber biomass are the prominent characters in the crop improvement program to maximize the cultivation output (Mariscal, Bergantin, & Troyo, 2002). The arrowroot plant produced the high yield tuber with high starch content for use in the starch industries is a purpose of the improvement program. Fresh tuber yield (FTY) and tuber biomass (TB) formed a sharp angle, indicated that the pair of parameters has a positive correlation. (Fig 2.). In other words, a higher tuber yield results higher tuber biomass. A negative correlation is shown by the pair of plant height (PH) and starch content (SC) which forms an obtuse angle. Bi-plot analysis separated the arrowroot populations in Garut District into five groups. BBC population formed the first group laid far away from the parameters of plant height, fresh tuber yield, tuber biomass, and starch content, indicated that these populations did not have the superiority on those parameters. Several populations, such as Sanding, Sodong, Banjarwangi, Cikelet, Kampung Jati, Gunung Sulah, Cisompet, Depok Lama, Cangkuang, Binong, Neglasari, Limbangan, and Cisandaan populations form the second group. They are laid around the coordinate center, indicating that these populations have the value of parameters in the vicinity of the average.

Cibatu and Munjul populations are the third group associated with starch content parameter, indicating that these populations have the higher value of starch content. Some populations are superior in fresh tuber yield and tuber biomass, i.e. Cikondang and Cikajang populations formed the fourth group. The last group is Cilawu population revealed the superior population for production of higher starch content and tuber biomass. Thus in general these three populations (Cilawu, Cikajang, and Cibatu) exhibit better characteristic than the others. In other words, these populations produce tuber of high quality and quantity.

## CONCLUSION

Arrowroot populations in Garut District showed the diversity in morpho-physiological characteristics, tuber yield and starch content revealed that transfer of plant material still occurs in local sites and the cultivation is not well developed. Growth parameters of arrowroot from Cilawu population had the highest values for seven characters, i.e. high growth, number of leaf, above growth biomass (leaf and stem biomass), and tuber biomass. Cikajang population recorded highest tuber yield followed by Cilawu population. Cibatu population produces the highest starch content followed by Cilawu population. The high heritability in a broad sense associated with high genetic advance was observed on fresh tuber yield indicated that selection on basis of these characters may be helpful to improve arrowroot tuber yield. Most of the growth traits had no significant correlation and indicated that the growth characteristics were not a good indicator for selecting the higher tuber production and starch content. Three populations (Cilawu, Cikajang, and Cibatu) have better tuber yield characteristics than the others to produce of high quality and quantity of arrowroot tuber.

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