Identification of stability and productivity the local red onion Palu based on the effect of genotype and planting location using a Structural Equation Model (SEM)

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Abstract: The effort to find superior varieties is initially by regarding the genotype and location because of these factors contribute to the significance of the interaction between genotype and location (GEI) on productivity. This study is important in plant breeding because the results can be used to predict and to select the genotypes that are stable and adaptable at different planting location. Paying attention to productivity is not sufficient in the GEI analysis to select superior varieties. As a result, a method such as Structural Equation Model (SEM) is needed to explain the effect of genotype and environmental factors on GEI. The obtained results based on the AMMI biplot showed that the genotypes of red onion which have stable productivity at five planting locations, namely Batu (G1) and Sanren F1 (G4). Furthermore, the genotype that is stable planted in five locations is Kawak (G7). The SEM output showed that physical characteristics affect the number of productivity. However, environmental factors such as altitude, soil physical and acid contribute to the productivity of the plant. Finally, we can conclude that the genotypes planted in low locations with soil pH greater than 6 and dusty loam soil conditions will provide more product of red onion with good quality.

1. Introduction

Central Sulawesi is one of the provinces in Indonesia which has great potential in the agricultural sector. This potential is supported by a good level of soil fertility, adequate availability of groundwater and rainwater, and a suitable climate (Ningsih et al., 2013). One of the agribusiness commodities that can be cultivated in Central Sulawesi is red onion which is a leading horticultural commodity in Central Sulawesi (Badan Litbang Pertanian, 2006).

The National Socio-Economic Survey (SUSENAS) states that the red onion consumption from 1981 to 2014 tended to increase with an average growth of 8.69% kg/cap/year. This data proves that the large demand and need for red onion which increases every year is not able to be followed by the production. This is due to limitations in crop cultivation, especially in terms of plant species diversity. The extension of the red onion plants in its growth is directed at the suitability of environmental physical factors optimally. In this regard, the availability of varieties that are in accordance with the local environment and the potential for high production is a factor that directly affects the production ability and adaptability of a variety (Ambarawati & Yudono, 2003).

The production ability is the accumulation of responses to various location conditions which are very complex characteristics and require an understanding of physiological aspects in analyzing them in an effort to find superior varieties (Djufry & Lestari, 2012). The effort to find superior varieties begins with paying attention to genotype factors (response from genotype) and location factors (response from location) because these two factors are components that contribute to the significance of GEI on production ability.
One way to assess the GEI is by conducting a production ability test experiment. This study is important in plant breeding because the results can be used to predict and select genotypes that are stable at different planting location or adaptable at a specific planting location. The method used in assessing GEI is the analysis of Additive Main-Effect and Multiplicative Interaction (AMMI) (Gauch & Zobel, 1996). However, paying attention to production ability only in the GEI analysis is not sufficient in order to select the stable superior varieties in different locations. As a result, we need a method that provides an explanation of the influence of genotype and environmental factors on the significance of GEI for production ability components and productivity, namely Structural Equation Model (SEM) (Jaya, 2009).

SEM is an approach that carries out simultaneous analysis of a system of equations where each equation describes a causal relationship between exogenous and endogenous variables that are included in the system. SEM is used to model the relationship between production ability components and productivity. SEM can also be used to test models with several exogenous variables, incorporate measurement errors and is able to partially test path coefficients (Jaya, 2009). Thus, with its ability to accommodate variables that are not the result of measurements from an observed variable, SEM is very effective in identifying the red onion local Palu which is stable and has high production based on genotype and location factors.

2. Research methodology
2.1. Type of research
This research is experimental design research. The research aims to identify the red onion local Palu that is stable and has high production, and the genotypes and location factors that are significantly affected. The research obtained will provide the genotype/variety red onion local Palu which is superior among several red onion varieties. Superior interprets in this study as a genotype that can adapt to several locations by taking into account the influencing factors of genotype and location.

2.2. Design experiment

Table 1. Research variable

| Variable                      | Unit          |
|-------------------------------|---------------|
| Tuber Weight (TW)             | Gram (gr)     |
| Tuber Diameter (TD)           | Centimeter (cm) |
| Number of tuber (NT)          | Piece         |
| Height of location (HL)       | Meter (m)     |
| Soil physical characteristic (SPC) | 1=sandy loam  |
|                               | 2=dusty loam  |
| Acidity (PH)                  | >7.0 = alkaline soil |
|                               | <7.0 = acid soil |
| Product (PDT)                 | Kilogram (kg) |

The data used in this study are primary data obtained from the experiment of research on the red onion. The population used in this study is the location of red onion planting in Central Sulawesi and the genotype of red onion in Indonesia. The sample used in this study is the planting location in Sigi and Donggala, and five red onion genotypes were selected subjectively by researchers. The selection of the red onion genotype was chosen because the researchers wanted to see the differences in the genotype results of red onion originating from Central Sulawesi and outside Central Sulawesi. The variables used in this study are given in Table 1. Table 2 provides the genotypes and planting locations.
Table 2. Research genotypes and planting locations

| Genotypes/Varieties | Locations     |
|---------------------|---------------|
| Batu (G1)           | Wombo (L1)    |
| Kertas (G2)         | Guntarano (L2)|
| Kawak (G3)          | Bulupontu (L3)|
| Sanref F1 (G4)      | Oloboju (L4)  |
| Tuk-tuk (G5)        | Soulove (L5)  |

2.3. Research location
The research location was conducted in five villages which produces red onion, around the city of Palu, namely Wombo, Guntarano, Bulupontu, Oloboju, and Soulove.

2.4. Data analysis
The process to conduct the data analysis is given in Figure 1 as follows:

![Figure 1. The flowchart of data analysis process](image-url)
3. Results and discussion

3.1. Data exploration

There are several production ability components of red onion that will be investigated in this study, namely tuber weight, tuber diameter, and number of tubers as well as the red onion productivity. The production is one of the agronomic characteristics of red onion plants that were measured after harvest with a kilogram unit. From the five genotypes that were planted at 5 different locations, the average production varied between genotypes. Figure 2 shows that the genotype which produces the lowest is the Sanren F1 (0.25 kg) planted in Guntarano. Moreover, a genotype that produces the highest is the Kertas, planted in Wombo with an average production is 2.30 kg.

Figure 2 describes the Tuk-tuk genotype which was planted in Guntarano has the lowest tuber weight (1.21 gr), while the Kertas has the heaviest tuber weight which grown in Oloboju with an average is 10.75 gr. Also, the Tuk-tuk genotype has the smallest tuber diameter (0.75 cm/location) planted in Guntarano. Moreover, the Kertas Genotype has the largest tuber diameter (3.36 cm/location) planted in Wombo. Furthermore, for production ability components for the number of tuber shows that the Kertas has the lowest which is planted in Oloboju (5 tubers), while the Tuk-tuk genotype has the highest number (11 tubers) planted in Wombo.

3.2. Analysis of variance

Analysis of variance is used to test the production ability components and the productivity of red onion using the complete randomized block design. The results show that the genotype and the environment have a significant effect on the production ability components (weight, diameter, and the number of tuber). Moreover, the genotype and the environment have a significant effect on the productivity of red onion. This indicates by the p-value smaller than α (0.05). Besides, the interaction between the genotype and the environment has an influence on the production ability components and productivity. These results can explain that there is any difference in the average production of red onion from genotypes which are planted in different environments. Consequently, conducting an AMMI analysis is necessary.
to find out what genotypes can adapt well and can be stable in certain locations by investigating the production ability components and the productivity of red onion.

### 3.3. AMMI analysis

The AMMI analysis was carried out to identify the locations that interact positively on certain genotypes in increasing the productivity of red onion. The first step includes the AMMI analysis is to describe the effect of the interaction between genotype and location using Singular Value Decomposition (SVD) in principal component analysis (PCA). The four PCA which were obtained with their eigenvalue are 3.638, 1.615, 1.178, and 9.5718 respectively. These values indicate that the contribution of the diversity effects the interaction between genotype and environmental. This can be explained by each of the principle components, 72.93%, 14.37%, 7.65%, and 5.05%.

#### Table 3. Analysis of Variance AMMI for Red Onion production

| Source               | df | SS    | MS    | F      | P-value |
|----------------------|----|-------|-------|--------|---------|
| Location             | 4  | 354.94| 88.736| 75.589 | 0.000   |
| Genotype             | 4  | 114.22| 28.554| 24.323 | 0.000   |
| Block                | 2  | 0.27  | 0.134 | 0.114  | 0.893   |
| Genotype * Location  | 16 | 54.54 | 3.409 | 2.904  | 0.002   |
| IPC 1                | 7  | 2.987 | 0.427 | 11.075 | 0.000   |
| IPC 2                | 5  | 0.359 | 0.072 | 1.861  | 0.119   |
| IPC 3                | 3  | 0.267 | 0.089 | 2.314  | 0.088   |
| IPC 4                | 1  | 0.031 | 0.031 | 0.804  | 0.375   |
| Error                | 48 | 56.35 | 1.174 |        |         |
| Total                | 74 | 580.32|       |        |         |

The determination of the number of IPC applies *Postdictive Success* method. This method used to obtain the number of axes that are significant on the F test of the AMMI variance analysis. Based on the results of the F test, the first IPC (IPC1) is only significant where the value $F_{cal}(22.681) > F_{table}(2.1026)$. As a result, the AMMI model is able to explain the diversity of interaction effects for the GEI of the red onion production with the value is 72.93%. In addition, the AMMI2 Biplot along with the elliptical confidence interval was used for the purpose of stability analysis and adaptability. The AMMI-2 biplot is a plot between IPC1 and IPC2 which describes the structure of the interaction between genotype and the environment.

![AMMI-2 Biplot and Confidence Interval of IPCA](image-url)

*Figure 3. AMMI-2 biplot and confidence interval of IPC for the red onion production*
Figure 3 provides the AMMI-2 biplot for the production ability of red onion. This can describe the diversity of interaction between genotype and environmental by the value is 72.93%. This value is greater than 50% showing the diversity of interactions.

Figure 3 shows that there are two genotypes that have relatively stable of the red onion production. These are Batu (G1) and Sanren F1 (G4) which were planted in Sigi and Donggala. The genotypes that have stable production are genotypes whose position is inside the ellipse of the center point (0,0). The Kertas (G2), Kawak (G3), and Tuk-tuk (G5) are genotypes which lay outside of the ellipse, far from the main axis and the location line. These results indicate that the three genotypes tends to be unstable or could not adapt well to the five planting location.

3.4. GEI analysis using SEM
The Structural Equation Model (SEM) will be combined with AMMI analysis to provide an explanation of factors that significantly affect the interaction between the genotype and location. These factors are from the production ability components, the genotype and the environmental. The factors are also considered to have an important role in explaining the interaction between genotype and location, especially in finding superior varieties. A comprehensive explanation of how the GEI of production ability influenced by several GEI of production ability components, productivity and the combination of genotype covariates with location covariates will be explained by combining the AMMI and SEM. The method then called SEM-AMMI. In SEM, the Partial Least Square (PLS-SEM) technique is used with a formative indicator model [7].

The SEM analysis involves exogenous and endogenous variables. The exogenous variable, in this case, is the interaction between the genotype covariate and the location/environment covariate, while the endogenous variable is the GEI for the production ability components and the GEI for the productivity of red onion. The formation of a path diagram in the indicator model uses a formative model. As a result, the direction of the causality relationship is from the indicator to the latent variable. The production ability components of the red onion involved in this study are tuber weight, tuber diameter and the number of tuber.

![Figure 4. Path diagram of SEM-AMMI](image)

Figure 4 shows the results of the SEM cross diagram from the SEM-AMMI modelling. Figure 4 gives the value of the loading factor (outer loading), path coefficients (inner path) and the value of R square as the standard values for the model. In order to know whether the model obtained is fit or not,
then an evaluation to the model will be carried out by investigating the goodness of fit of the model (Bentler & Bonnet, 1980). Table 4 provides the results of the goodness of fit of SEM.

| Table 4 | The goodness of fit of the model
|---------|------------------|
| **Criteria** | **Fit** |
| SRMR | 0.087 | SMSR<0.1 | Good fit |
| Chi-Square ($\chi^2$) | 127.694 | $\chi^2_{cal} > \chi^2_{tab}$ | Good fit |
| NFI | 0.793 | 0.08 ≤ NFI < 0.9 | Marginal fit |

Table 4 gives the results of the goodness of fit of the model that has been formed. It can be seen that the SRMR value is 0.087. This value is less than 0.1 meaning that the model has a good fit. Furthermore, the value of $\chi^2_{cal}$ (116.44) is greater than the value of $\chi^2_{tab}$ (35.17). This indicates that the model is good fit. The NFI value is closer to 1 meaning that the better of the goodness of fit. The NFI value obtained is 0.793 meaning that 0.08 ≤ NFI < 0.9. This value indicates that the model is marginal fit.

The values of the goodness of fit which satisfy the criteria of good fit indicating that the developed model is able to explain the dispersion of data. The results show that the data is spread well. This means that the analysis of the results can be accepted. Table 5 provides the direct effect, indirect effect, and total value the goodness of fit.

| Variable | Direct Effect | Indirect Effect | Total |
|----------|--------------|----------------|-------|
| Latent variable $\eta_1$ according to TW (Tuber Weight) | -0.042 | -0.398 | -0.440 |
| Latent variable $\eta_2$ according to TD (Tuber Diameter) | -2.238 | -0.427 | -2.665 |
| Latent variable $\eta_3$ according to NT (Number of tuber) | -0.443 | - | -0.443 |
| Covariate TW × Location factors | 0.355 | 0.580 | 0.935 |
| Covariate TD × Location factors | 2.667 | 0.547 | 3.214 |
| Covariate NT × Location factors | 0.688 | 0.53 | 1.218 |

SEM analysis shows that the significant effect of GEI in multi-location experiments is influenced by the GEI of tuber weight, tuber diameter and the number of tubers. These give the direct effect (Table 5) with the values being -0.042, -2.238, and -0.443 as can be seen in Figure 3. The three GEI of production ability components (tuber weight, tuber diameter and the number of tuber) have a negative direct effect on the productivity of GEI. These results indicate that the three production ability components will produce the red onion less. In addition, it can be seen that the GEI for tuber weight has an indirect effect through the diameter and number of tubers with the value is -0.398. The GEI for tuber diameter has an indirect effect through the number of tubers with the value is -0.427. The total effect from the three GEI of the production ability components was -0.440 for the GEI of tuber weight, -2.665 for the GEI of tuber diameter, and -0.443 for the GEI of the number of tuber. From the SEM path diagram in Figure 4, it can also be seen that the diversity of the GEI for each production ability component is 0.956 for tuber weight, 0.961 for tuber diameter and 0.957 for tuber number. The obtained values indicate that the analyzed model can explain the relationship between the GEI of production ability components with the influenced factors of genotype and location on GEI productivity.

The covariate interaction of tuber weight (TW) × covariate location factor gave an effect on the production ability component of tuber weight of 0.978. These results indicate that the genotypes planted in the low location, the soil PH greater than 6 and the dusty loam soil condition will produce heavy tuber...
weight of red onion. The covariate interaction of tuber diameter (TD) × covariate location factor gave an effect on the production ability component of tuber diameter of 0.974. This shows that the genotypes planted in the low location, the soil PH greater than 6 and the dusty loam soil condition will produce large tuber diameter. The covariate interaction the number of tubers (NT) × covariate location factor provided an effect on the production ability component of the number of tuber with its value is 0.973. This value determines that the genotype planted in the low location, the soil PH greater than 6 and the dusty loam soil condition will produce the large number of tuber.

4. Conclusion
The AMMI biplot shows that the genotypes have stable red onion production ability planted in five locations are Batu (G1) and Sanren F1 (G4). Moreover, the genotypes have stability in producing red onion tuber weight (TW) planted in five locations are Batu (G1) and Sanren F1 (G4). This was indicated by their tuber weight are above average. As a result, these two genotypes will produce more red onion than other genotypes. On the other side, the genotypes that were relatively stable in producing the diameter of tuber (TD) planted in five locations are Sanren F1 (G4) and Tuk-tuk (G5). In addition, Kawak (G7) genotypes that were relatively stable in order to produce the number of tuber (NT) of red onion. The SEM outputs show that the physical characteristics of the red onion genotype greatly affect the production ability. However, the production ability is also influenced by the environmental factor such as altitude, soil physical and acidity of the soil. Finally, we can conclude that the genotypes planted in a low location with soil PH greater than 6 and dusty loam soil conditions will produce more red onion with good physical quality. For further work, the season factors can be used as a covariate of environmental factors. Moreover, the water content of red onion tuber can be used as a component of the red union production ability to increase the GEI on productivity.

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