Evaluation of sweet sorghum (*Sorghum bicolor* L. [Moench]) on several population density for bioethanol production

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Abstract
Sweet sorghum (*Sorghum bicolor* L. [Moench]) crop management that is use for raw source of bioethanol for industrial purpose in Indonesia is less developed. The aim of this research was to evaluated sweet sorghum variety at several population to determine optimum density for juice production. Experiment design was set on split-plot design with three replications, conducted on August to December 2016 at the Indonesian Cereals Research Institute Research Station, Maros South Sulawesi. Main plot were six variation of plant row, and sub plot were three sweet sorghum varieties. Result of the study showed that plant population was high significantly affect to stalk weight, total biomass yield, leaf weight, and also significantly affect bagass weight and juice volume. Varieties were high significantly different in plant height, juice volume, and number of nodes. Super 1 variety on population at 166,667 plants/ha (P1) was obtained the highest juice volume (19,445 l Ha⁻¹), meanwhile the highest brix value obtained from Numbu at the same plants population. Furthermore juice volume had significant correlation with biomass weight at the r=0.73. Based on ethanol production, Super 2 and Numbu had the highest volume at 83.333 plants/ha density (P5) and Super 1 at 166,667 plants/ha density with the ethanol volume were 827.68 l Ha⁻¹, 1116.50 l/ha and 993.62 l Ha⁻¹ respectively.

Keywords: sweet sorghum, population, biomass, bioethanol.

1. Introduction
Sweet sorghum has many advantages compared to other cereals food crops, regarding to its funcionally to serve as a source of food, feed and also bioenergy sources (1). Sorghum is main staple for more than 500 million people in 30 semi arid countries (2). This sweet sorghum stalk contains approximately equal soluble (glucosa and sucrosa) and insoluble (celullosa and hemicelullose) carbohydadr and has been considered as promising alternative feedstock from by product of bioethanol production in simple and easy way (3) (4). Sweet sorghum is efficient C-4 photosintetic pathway, requireless fertilizer and water intake, possibility of multiple cropping per year, it is resilient to able to grow on marginal area especially drought prone area, has ratoon capability, wide adaptability geographic, and huge potential breeding (5) (6) (7). Sorghum flour fractions from its grain (whole and decorticated flour and bran) were evaluated by (8) for diet induced obese rats for oxidative stress and obesity parameters. Sorghum flour fractions reduced liver fat and whole sorghum flour decreased fasting glucose, improved glucose tolerance, insulin resistance and reduced insulin secretion compared
to high fat-fructose groups. Sorghum flour showed a slight improvement in antioxidant status. This result might be applied for human being.

Beside grain production, sweet sorghum juice is a potential source for bioethanol, which can directly mixed with gasoline, or react with isobutylene to form of ethyl tert-butyl ether (ETBE), an octane additive for gasoline (9). Another research, by Barcelos et al. (2016) reported that under optimum hydrolysate with Saccharomyces cerevisiae strain, the result of ethanol was 87 g L\(^{-1}\). from stalk juice, concentration of ethanol produced from bagasse was 72 g L\(^{-1}\), after acid pre treatment to remove hemicelullose and hydrolysis and a flocculant of strain Scheffersomyces stipitis was used for fermentability of the hemicellulosic hydrolysate for the 23 hours pre treatment, yielded ethanol at 30 gL\(^{-1}\) concentration.

Sweet sorghum cultivation for bioenergy production is an attractive option to cope challenges of climate changes (11). Appropriate cropping technique option will increasing yield per hectare. Commonly, sorghum planting spaces is 70 cm x 25 cm between row to achieve population at 57,147 plant per ha (12) and 75 cm x 25 cm to gain 53,333 plant per ha (13). The result of Irwan et al. (2005) experiments showed that narrow plant row (50 cm x 30 cm) at 133,333 plant ha\(^{-1}\) population provide higher biomass yield compared to wider plant row (75 cm x 25 cm) at 106,666 plant Ha\(^{-1}\) population. Furthermore, Enciso et al. (2015) also reported at the water level 336-380 mm per year, high population 292,000 plant Ha\(^{-1}\) per ha resulted 58.9 t Ha\(^{-1}\) biomass.

The objective of this study was to evaluate optimum population of three sweet sorghum variety to get highest biomass productivity for bioethanol production.

2. Materials and Methods

The experiment was carried out in Indonesian Cereals Research Institute (ICERI) research station Sweet sorghum seed was planted on August 2016 and harvested on December 2016. Split Plot Experimental Design was used with three replications. Sub Plot was three sweet sorghum varieties Super-1, Super-2 and Numbu. Main Plot was six variation population arrangement: P1= plant row 60 cm x 10 cm = 166,667 plantHa\(^{-1}\), P2= plant row 60 cm x 15 cm = 111,111 plantHa\(^{-1}\), P3=plant row60 cm x 20 cm = 83,333 plantHa\(^{-1}\), P4=plant row70 cm x 10 cm = 142,857 plantHa\(^{-1}\), P5=plant row70 cm x 15 cm = 95,238 plant per ha, P6=plant row 70 cm x 20 cm = 71,429 plantHa\(^{-1}\).There were18 treatments combination and each treatment combination was planted on 5 m x 9 m plot square, with each plot distance to another was 1 m, so all treatment combination was laid on 3,115 m\(^2\) of land.

![Figure 1](image.png)

**Figure 1.** Rainfall intensity and rainfall days data during crops season on ICERI research station Maros, 2016.

The fertilizer dosage of nitrogen, phospat and potassium was 112,5 kgHa\(^{-1}\) N, 100 kgHa\(^{-1}\) P and 75 kgHa\(^{-1}\) potassium (K). Fertilizer applied in urea form (source of N) and compound fertilizer
The parameter in this observation were plant height (cm), stalk diameter (mm), node number, yield in stover biomass and stalk biomass measured in weight (tHa⁻¹), leaf biomass weight (tHa⁻¹) sugar percentage (% brix), and ethyl alcohol was measured with alcohol relative meter. Data recorded on the plant age at 105 DAP and 110 DAP.

2.1 Stalk harvesting and Juice Processing

Stalk biomass harvesting was performed by collecting 2 lines of sample plot in 4 m length (about 11-12 percent of the each plot area) at the plant age of 105 DAP and collect 4 rows sample row x 4 m length at 110 DAP sample collection. Number of stalk collected from 110 DAP crops was P1 and P4 = 160; P2 and P5 = 107; P3 and P6 = 80, number of stalk collected from 105 DAP crops was P1 and P4 = 80; P2 and P5 = 54; P3 and P6 = 40). Biomass measured directly after harvesting to record biomass weight. Sorghum plants were then cleaned manually using knife to discard the leaves, sheath and then to be measured again to record clean stalk weight. The next process was to extract cleaned stalk into mechanically for three times, then measured the juice volume. Brix percentage and relatif alcohol percentage observed immediately after fresh juice obtained using digital brix refractometer and ethyl alcohol refractometer.

2.2 Juice Fermentation

Forty litre sweet sorghum juice was collected into drum for the fermentation process. During juice fermentation process, maximum brix value have to be at 14%, if the brix value of juice more than 14%, water was added to dilute and reduce brix. However if brix value were less than 14% adding sugar was required until brix value reached 14%. After yeast from Saccharomyces cerevisiae strain added, urea and NPK were put into the fermentor, with 40 litre capacity and fermentation minimum for 7 days until the brix value declined to 4.5%-5.5%.

2.3 Distillation

Fermented juice poured into destilator drum, and gas stove was used for heating until temperature reached 80°C (destilation temperature). Ethanol will then drip after required temperature reached. The destilation temperature maintained stable by controlling stove fire until alcohol drips were stopped.

2.4 Statistical Analysis

Sweet sorghum was grow in a split plot experimental design which included 18 combination of six plants densities x three varieties in three replicates each combination. The data were subjected to two-way ANOVA followed by a Least Significant Different Test of means test was used to determine if means were significantly different (α=0.05) from each other. Statistical analysis was conducted with the software package SAS 9.3. Correlation test were used to determine the relationship between variables.

3. Results and Discussions

3.1 Statistical analysis result

Mean square of agronomic character, yield and yield components of sweet sorghum at 110 DAP and 105 DAP showed on table 1. Interaction within main plot (plant population) and sub plot (sweet sorghum variety) on the all parameter was not significant based on ANOVA analysis. Sweet sorghum variety were highly significant to ethyl alcohol contain at 110 DAP, plant height, node
number and panicle weight 105 DAP, highly significant to brix value at 110 DAP, stalk diameter, leaf weight, biomass weight, brix value and ethyl alcohol percentage.

Population highly significant to plant height, stalk diameter, node number and leaf weight, brix value, ethyl alcohol and juice volume at the 110 DAP harvest. Results at the 105 DAP harvest showed that, population had highly significant to stalk weight, bagasse weight, ethyl alcohol and significant on juice volume. Interaction between population and replication result were significant with bagasse weight, ethyl alcohol percentage and juice volume. This result is contrast to (16), which reported that sorghum plant density was not affected significantly to plant height or dry matter yield at either harvest, but did all dry matter digestibility at early heading. According to (17) experiment suggested that high density combined with water deficit supply could affected to decrease dry mass of sorghum.

**Table 1.** Mean square of yield and yield component sweet sorghum at 110 DAP and 105 DAP harvested age.

| Source of Variation | Replication (R) | Population (P) | P*R | Variety (V) | P*V |
|---------------------|-----------------|----------------|-----|-------------|-----|
| Harvest at 110 DAP  |                 |                |     |             |     |
| Plant height        | 184.32 ns       | 7182.62 **     | 820.21 ns | 1313.49 ns | 814.58 ns |
| Stalk diameter      | 1.52 ns         | 8.68 **        | 1.16 ns | 2.40 *      | 0.65 ns |
| Node number         | 8.21 **         | 11.58 **       | 1.82 ns | 1.35 ns     | 1.19 ns |
| Biomass weight      | 1.66 ns         | 6.66 ns        | 1.56 ns | 2.66 ns     | 3.11 ns |
| Stalk weight        | 1.04 ns         | 4.34 ns        | 1.92 ns | 2.16 ns     | 1.11 ns |
| Leaves weight       | 0.22 ns         | 1.08 **        | 0.29 ns | 0.07 ns     | 0.08 ns |
| Bagasse weight      | 2.20 **         | 0.59 ns        | 0.12 ns | 0.85 ns     | 0.32 ns |
| Brix                | 2.57 ns         | 15.65 **       | 1.04 ns | 4.37 *      | 0.52 ns |
| Ethyl Alcohol       | 11.05 ns        | 149.24 **      | 9.66 ns | 28.95 **    | 5.08 ns |
| Juice volume        | 355801.39 tn    | 6258837.50 **  | 176697.22 tn | 201359.72 tn | 307993.06 tn |

| Harvest at 105 DAP  |                 |                |     |             |     |
| Plant height        | 62.57 ns        | 106.65 ns      | 456.95 ns | 11245.35 ns | 284.20 ns |
| Stalk diameter      | 21.35 **        | 9.27 ns        | 1.86 ns | 12.52 *     | 2.83 ns |
| Node number         | 4.02 **         | 1.23 ns        | 0.26 ns | 14.69 **    | 0.26 ns |
| Biomass weight      | 787.63 *        | 489.90 ns      | 388.74 ns | 25.80 ns    | 90.57 ns |
| Stalk weight        | 90.02 ns        | 313.31 **      | 106.02 ns | 188.35 ns   | 45.62 ns |
| Panicles weight     | 1.06 ns         | 1.11 ns        | 0.63 ns | 12.39 **    | 1.17 ns |
| Leaves weight       | 9.39 *          | 6.36 ns        | 4.08 ns | 9.39 *      | 1.94 ns |
| Bobot Bagasse       | 13.72 ns        | 68.74 **       | 36.03 * | 56.17 *     | 13.61 ns |
| Brix                | 1.97 ns         | 2.90 ns        | 0.84 ns | 6.97 *      | 0.88 ns |
| Ethyl Alcohol       | 13.72 ns        | 68.74 **       | 36.03 * | 56.17 *     | 13.61 ns |
| Juice volume        | 8282936.70 ns   | 19536564.40 *  | 18338705.40 | 167599682.10 * | 8945163.20 ns |

ns=not significant.

3.2. Yield in juce volume and biomass form

Data in table 2, showed that juice volume rate from sweet sorghum stalk at 110 DAP harvested age were highest at P1V1 treatment which resulted 19,445 l/ha. The next highest result were obtained on P3V3 treatment non significantly different to P2V3 and P3V1 treatment with the juice volume result 18,796 l/ha 18,315 l/ha and 17,648 l/ha. Different result of juice volume were obtained from 105 DAP harvested age with the value 15,555 l/ha, and P1V1 resulted 14,546 l/ha respectively non significantly different to other treatments. The data suggested that juice volume was affected by population. High population tends to increase juice volume.

Juice volume derived from sweet sorghum stalk at the 110 DAP harvested age were higher than juice volume at the 105 DAP harvested age which average resulted at 14,488.72l/ha compare to 11,739.33 l/ha respectively. The 110 DAP plant age is physiology mature for grain, harvesting sorghum at this age will optimize the result of yield both from grain and also from stalk. Brix and ethyl
alcohol percentage were declined for 0.28% and 3.15% respectively. Declined of sugar content in sorghum juice assumed that trigger by stalk plant tissue were aging.

Table 2. Juice volume, brix, ethyl alcohol of sweet sorghum on 105 DAP and 110 DAP harvested age.

| Treatment Combination | 105 DAP | 110 DAP |
|-----------------------|---------|---------|
|                       | Juice Volume (l/ha) | Brix (%) | Ethyl alcohol (%) | Juice Volume (l/ha) | Brix (%) | Ethyl alcohol (%) |
| P1V1                  | 14546.00 | 14.83 ab | 40.00 ab | 19445.00 a | 13.73 c-f | 33.37 c-e |
| P1V2                  | 12222.00 | 15.33 ab | 42.40 a | 11759.00 c-e | 16.27 ab | 44.43 a |
| P1V3                  | 11667.00 | 17.17 a  | 43.93 a | 15185.00 a-d | 16.47 a | 43.20 ab |
| P2V1                  | 10648.00 | 14.50 b  | 37.40 ab | 16019.00 a-c | 12.97 ef | 32.40 c-e |
| P2V2                  | 11611.00 | 14.77 b  | 41.87 a | 8796.00 e | 15.43 a-d | 40.33 a-d |
| P2V3                  | 14259.00 | 15.97 ab | 46.00 a | 18315.00 ab | 14.77 a-f | 37.03 a-e |
| P3V1                  | 12778.00 | 13.90 b  | 36.77 ab | 17648.00 ab | 13.47 d-f | 31.60 de |
| P3V2                  | 11213.00 | 13.80 b  | 39.50 ab | 14445.00 a-d | 13.97 b-f | 34.67 b-e |
| P3V3                  | 15555.00 | 15.57 ab | 38.83 ab | 18796.00 ab | 15.40 a-d | 39.10 a-e |
| P4V1                  | 12619.00 | 15.07 ab | 43.10 a | 15183.00 a-d | 15.37 a-d | 35.27 a-e |
| P4V2                  | 8444.00  | 15.70 ab | 41.83 a | 10397.00 de | 15.87 c-e | 41.33 a-c |
| P4V3                  | 10794.00 | 15.57 ab | 39.43 ab | 14047.00 b-d | 15.07 a-e | 38.03 a-e |
| P5V1                  | 11587.00 | 14.83 ab | 39.70 ab | 14397.00 a-d | 14.87 a-f | 36.23 a-e |
| P5V2                  | 10397.00 | 13.70 b  | 38.67 ab | 11587.00 c-e | 15.13 a-e | 38.30 a-e |
| P5V3                  | 12619.00 | 14.80 ab | 40.60 ab | 14127.00 b-d | 13.33 d-f | 31.57 de |
| P6V1                  | 8889.00  | 14.57 b  | 38.93 ab | 15095.00 a-d | 14.73 a-f | 36.13 a-e |
| P6V2                  | 8730.00  | 14.20 b  | 29.73 b  | 8810.00 e | 12.60 f | 29.77 e |
| P6V3                  | 12730.00 | 15.00 ab | 37.57 ab | 16746.00 a-c | 14.80 a-f | 36.87 a-e |

Mean | 11739.33 | 14.96 | 39.79 | 14488.72 | 14.68 | 36.65 |
StDev | 1953.49 | 0.86 | 3.49 | 3200.32 | 1.11 | 4.08 |
Min | 8444.00 | 13.70 | 29.73 | 8796.00 | 12.60 | 29.77 |
Max | 15555.00 | 17.17 | 46.00 | 19445.00 | 16.47 | 44.43 |
CV | 31.45 | 8.09 | 14.63 | 18.38 | 8.02 | 12.86 |

Same letter means no different between values in the same column.

3.3. Total biomass weight and stalk weight

Sweet sorghum biomass at 110 DAP harvested age were decreased 0.05 t/ha-1 compared to 105 DAP harvested age, however stalk weight increased 3.07 t/ha-1 (table 3). This result describe that there was soft tissue stalk were formed into hard tissue stalk. Biomass weight at 105 DAP harvested age were ranged at 40 t/ha-1 at P6V2 to 68.33 t/ha-1 P1V3. Highest stalk weight at 105 DAP harvested age was obtained by P1V2 treatment (47 t/ha-1) and was not significantly different to P1 dan P2 all three variety, also to P3V3, P4V1, P4V3, P5V2 and P5V3 treatment. It was showed that at 105 DAP harvested age, the result at dense population (≥ 95,238 plants/ha) higher than less population (≤ 71,429 plants/ha). This result was contrast to (18) experiment result, which suggested that biomass weight has sharply reduced by increasing of plant densities.

Non significant result were obtained from total biomass weight at 105 DAP harvesting. The P1V2 treatment was highest result of stalk weight from 105 DAP harvesting(47 t/ha-1). Highest total biomass weight at 110 DAP were obtained from P1V3 treatment with the result 80.67 t/ha-1. Stalk weight at 110 DAP yield were ranged from 26.67 t/ha-1 – 56.67 t/ha-1, and the highest result were P1V2 and P1V3. Hemicelulosa B and cellulose-rich residue (CRF) which is isolated from sorghum biomass are useful as oil-in-water emulsifier and water holding agent respectively. Those product is considered economical as they are isolated from by product of sweet sorghum processing for making biofuel or directly from the sorghum biomass and also from the by products of sorghum grains milling (18).
Table 3. Total biomass weight and stalk weight 105 DAP and 110 DAP of sweet sorghum yield

| Treatment Combination | Total biomass weight 105 DAP | Stalk weight 105 DAP | Total biomass weight 110 DAP | Stalk weight 110 DAP |
|-----------------------|-----------------------------|----------------------|-----------------------------|----------------------|
| P1V1                  | 58.33 a                     | 41.00                | 68.00 abc                   | 40.67 ab             |
| P1V2                  | 66.00 a                     | 47.00 a              | 79.33 ab                    | 56.67 a              |
| P1V3                  | 68.33 a                     | 43.00 ab             | 80.67 a                     | 56.67 a              |
| P2V1                  | 46.00 a                     | 35.00 a-c            | 43.00 cd                    | 32.33 b              |
| P2V2                  | 57.67 a                     | 37.67 a-c            | 49.67 cd                    | 40.33 ab             |
| P2V3                  | 51.00 a                     | 38.00 a-c            | 55.67 b-d                   | 41.67 ab             |
| P3V1                  | 41.33 a                     | 30.00 bc             | 41.67 cd                    | 31.00 b              |
| P3V2                  | 50.00 a                     | 27.67 bc             | 49.00 cd                    | 36.67 b              |
| P3V3                  | 51.33 a                     | 37.33 a-c            | 50.33 cd                    | 34.00 b              |
| P4V1                  | 59.33 a                     | 36.67 a-c            | 48.33 cd                    | 36.00 b              |
| P4V2                  | 52.00 a                     | 28.33 bc             | 56.00 b-d                   | 40.67 ab             |
| P4V3                  | 58.00 a                     | 43.33 ab             | 47.67 cd                    | 37.00 b              |
| P5V1                  | 46.00 a                     | 27.33 bc             | 48.00 cd                    | 35.67 b              |
| P5V2                  | 46.00 a                     | 31.33 a-c            | 50.67 cd                    | 36.33 b              |
| P5V3                  | 48.67 a                     | 38.00 a-c            | 47.33 cd                    | 36.00 b              |
| P6V1                  | 52.67 a                     | 21.67 c              | 38.00 d                     | 26.67 b              |
| P6V2                  | 40.00 a                     | 28.00 bc             | 40.00 d                     | 30.00 b              |
| P6V3                  | 40.67 a                     | 29.00 bc             | 39.00 d                     | 27.33 b              |

Mean: 51.85, StDev: 8.17, Min: 40.00, Max: 68.33, CV: 27.36

same letter means no different between values in the same column

3.4. Plant growth and by product

Data in table 4 shows that 105 DAP harvest crops with the highest stalk obtained at P1V2, P4V2, and P6V2 treatment with 317.33 cm, 316.67 cm and 312.33 cm height respectively. At 110 DAP harvested age, the highest plant weight was obtained at P5V2 treatment, which also had large stalk diameter compared to the other treatments and average node number were more than other treatments with each valued (362.27 cm, 19.7 mm and 13.87 node). In the P2V2 treatment, the stalk diameter (20.27 mm) and the average number of sections (14.07 nodes) had the highest value compared to other treatments, as well as at plant height parameter, P2V2 treatment produced a higher stalk than other treatments. Based on the data in table 1, plant height, stalk diameter and number of node at age 105 DAP and stalk diameter at age 110 DAP were more affected by varieties than plant spacing treatment, so for those parameters, it can be concluded that V2 (Super 2) is superior compared to two other varieties.

Varieties were affect to sorghum plant height, V2 (Super 2) considered as higher plant compared to other varieties under various densities. At the other cropping system, the result of (19) experiment suggested that intercrop sorghum x cowpea reduce height than sorghum sole. Plant height supported by node number and length of stem between nodes, rate of Super 2 nodes number was 13.35 whereas Super 1 and Numbu was 11.47 dan 12.76 respectively.
Table 4. Agronomic components of plant height, stalk diameter, and node number of sweet sorghum at 105 DAP and 110 DAP age.

| Treatment combination | 105 DAP | 110 DAP |
|-----------------------|---------|---------|
|                       | Plant height | Stalk diameter | Node number | Plant height | Stalk diameter | Node number |
| P1V1                  | 267.67 b-d  | 19.67 a-c  | 11.00 d      | 289.47 d-g  | 15.77 b        | 10.73 f      |
| P1V2                  | 317.33 a  | 22.67 a   | 13.00 a-c    | 336.73 a-c  | 18.97 ab       | 12.60 a-e    |
| P1V3                  | 252.00 cd  | 18.67 bc  | 12.67 a-c    | 266.77 f-h  | 21.77 a        | 12.83 a-d    |
| P2V1                  | 292.33 a-d | 20.00 a-c | 11.67 cd     | 301.33 c-f  | 18.20 ab       | 11.07 ef     |
| P2V2                  | 293.33 a-c | 21.33 a-c | 13.33 ab     | 339.43 ab   | 20.27 a        | 14.07 a      |
| P2V3                  | 259.00 b-d | 20.00 a-c | 12.67 a-c    | 261.27 gh   | 19.27 ab       | 13.43 a-c    |
| P3V1                  | 286.00 a-d | 20.67 a-c | 11.67 ed     | 316.67 b-d  | 19.30 ab       | 11.67 d-f    |
| P3V2                  | 296.67 ab  | 22.00 ab  | 12.67 a-c    | 325.50 b-d  | 20.67 a        | 13.50 ab     |
| P3V3                  | 250.67 d   | 23.00 a   | 12.67 a-c    | 259.43 gh   | 20.40 a        | 13.57 ab     |
| P4V1                  | 284.67 a-d | 17.67 c   | 11.00 d      | 292.83 d-g  | 19.23 ab       | 11.60 d-f    |
| P4V2                  | 316.67 a   | 20.33 a-c | 13.00 a-c    | 348.70 ab   | 19.47 a        | 13.03 a-d    |
| P4V3                  | 253.67 cd  | 19.33 a-c | 12.00 b-d    | 270.17 e-h  | 18.13 ab       | 11.70 d-f    |
| P5V1                  | 291.33 a-d | 20.33 a-c | 12.00 b-d    | 318.13 b-d  | 20.93 a        | 11.97 a-e    |
| P5V2                  | 297.67 ab  | 21.33 a-c | 13.67 a      | 362.27 a    | 19.57 a        | 13.87 a      |
| P5V3                  | 263.00 b-d | 21.33 a-c | 12.67 a-c    | 261.50 gh   | 20.10 a        | 12.63 a-e    |
| P6V1                  | 289.67 a-d | 21.00 a-c | 11.67 ed     | 303.50 c-e  | 19.80 a        | 11.80 c-f    |
| P6V2                  | 312.33 a   | 21.67 ab  | 14.00 a      | 350.63 ab   | 20.87 a        | 13.00 a-d    |
| P6V3                  | 257.33 bcd | 22.33 ab  | 13.33 ab     | 247.23 h    | 20.27 a        | 12.40 a-e    |
| Mean                  | 282.30     | 20.74     | 12.48        | 302.75      | 19.61          | 12.53        |
| StDev                 | 22.52      | 1.40      | 0.86         | 36.24       | 1.34           | 0.97         |
| Max                   | 250.67     | 17.67     | 11.00        | 247.23      | 15.77          | 10.73        |
| Min                   | 317.33     | 23.00     | 14.00        | 362.27      | 21.77          | 14.07        |
| CV                    | 7.54       | 9.09      | 5.82         | 6.26        | 9.59           | 6.77         |

same letter means no different between values in the same column

By product formed as empty panicle, leaf and bagasse from juice squeeze is presented in table 5. Bird pest attacks resulted in the number of panicles of 110 DAP reduced significantly, resulting in poor data processing. Highest leaves weight at 110 DAP crops weight were obtained at P1V3 combination treatment (25.73 tHa⁻¹), meanwhile highest panicle and bagasse weight at 105 DAP crops, and bagasse weight at 110 DAP crops obtained on P1V2 combination treatment.

Table 5. By product of ethanol production from sweet sorghum at the 105 DAP and 110 DAP crops age.

| Treatment combination | 105 DAP | 110 DAP |
|-----------------------|---------|---------|
|                       | Panicle weight | Bagasse weight | Panicle weight | Leaves weight | Bagasse weight |
| P1V1                  | 1.67 c  | 17.33 bc | 1.38 b  | 25.73 a | 19.92 b |
| P1V2                  | 5.33 a  | 27.33 a  | 3.84 a  | 18.62 a-c | 46.75 a |
| P1V3                  | 2.00 c  | 21.67 ab | 1.91 ab | 21.82 ab | 27.18 b |
| P2V1                  | 2.00 c  | 14.33 bc | 1.54 b  | 9.14 bc | 14.93 b |
| P2V2                  | 3.67 a-c | 17.00 bc | 3.01 ab | 7.04 c | 24.15 b |
| P2V3                  | 2.67 bc | 20.33 a-c | 1.83 ab | 11.72 bc | 18.60 b |
| P3V1                  | 3.00 bc | 14.33 bc | 2.11 ab | 8.30 bc | 12.08 b |
|          | P3V2  | P3V3  | P4V1  | P4V2  | P4V3  | P5V1  | P5V2  | P5V3  | P6V1  | P6V2  | P6V3  | Mean | StDev | Max   | Min   | CV    |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Rate     | 4.33  | 3.00  | 3.00  | 3.67  | 3.00  | 2.67  | 3.67  | 3.00  | 2.00  | 3.00  | 2.33  | 3.00  | 0.91  | 1.67  | 5.33  | 34.40 |
| Brix     | ab    | bc    | bc    | a-c   | bc    | ab    | a-c   | bc    | c     | bc    | bc    |        |       |       |       |       |
| Percentage| 18.33 | 15.67 | 18.33 | 20.33 | 20.67 | 16.33 | 17.67 | 16.00 | 14.33 | 15.33 | 13.67 | 17.72 | 3.41  | 13.67 | 27.33 | 22.36 |
| Ethanol  | 2.94  | 1.90  | 1.64  | 2.86  | 2.09  | 1.79  | 3.29  | 3.46  | 1.56  | 2.86  | 1.38  |        |       |       |       |       |
| Yield    | ab    | ab    | bc    | ab    | ab    | b     | ab    | ab    | b     | ab    | b     |        |       |       |       |       |
| Ab (%)   | 9.52  | 14.56 | 10.80 | 8.99  | 8.99  | 10.43 | 11.27 | 7.74  | 9.66  | 7.59  | 10.28 |        |       |       |       |       |
| BC (%)   | 16.65 | 14.37 | 18.93 | 23.77 | 16.17 | 15.04 | 16.37 | 15.35 | 12.70 | 15.16 | 10.83 |        |       |       |       |       |
| CV       |       |       |       |       |       |       |       |       |       |       |       |       | 34.40 | 22.36 | 48.19 | 57.43 |
|          |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | 54.04 |

Same letter means no different between values in the same column.

### 3.5 Ethanol production of sweet sorghum

Rate of brix percentage and ethyl alcohol during the fermentation time showed on figure 2. Brix percentage rapidly declined at the 2nd day of fermentation from 13.73 % to 8.98 % indicated that fermentation process were goes well. After 10 days of fermentation, liquid were transfered into destilation drum for the next step.

![Figure 2. Rate of brix percentage and ethyl alcoholduring fermentation process of bioethanol](image)

The result of ethanol production presented on figure 3. Ethanol production was lower than potential outcome based on previous study (5000 l Ha{\textsuperscript{-1}})(13). On the different process way, (20) study, reported ethanol 91.94 g per kg sorghum was acheived without any detoxification and washing of pre treated biomass after mild acid pretreatment followed by enzimatic hydrolisy and fermentation. The result of this study presented in diagram, higher ethanol production in the Numbu variety, followed by the Super-1 variety, and the lowest Super-2 variety. While based on plant spacing, the Numbu variety and the Super-2 varieties of ethanol production were relatively higher at 60 cm x 20 cm plant spacing, while the Super-1 varieties were higher at 60 cm x 10 cm. On the Super-2 variety showed ethanol yield the lowest despite the high stalk length and stalk weights, but the juice rendementof juice is lower.
Figure 3. Ethanol production at 70% level percentage of 110 DAP yield result on plant population combination treatment.

Highest significant correlation within sweet sorghum juice volume with all other parameters obtained with total biomass weight r=0.73 (presented on table 6). Positive correlation value indicated that total biomass weight influenced a increasingly of juice volume. The highest significant correlation on all parameters were within brix value and ethyl alcohol content which vauled r=0.91.

Table 6. Correlation of juice volume with other agronomic character

| Agronomic Variable | JV  | PH  | SD  | JN  | TBW | SW  | PW  | BBDr | BBgs | JlBt | Brix |
|--------------------|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|
| PH                 | 0.06ns |     |     |     |      |     |     |      |      |      |      |
| SD                 | -0.18ns | 0.25ns |     |     |      |     |     |      |      |      |      |
| JN                 | 0.04ns | 0.28* | 0.35* |     |      |     |     |      |      |      |      |
| TBW                | 0.73** | 0.23ns | 0.13ns | 0.37** |     |     |     |      |      |      |      |
| SW                 | 0.60** | 0.13ns | -0.02ns | 0.23ns | 0.68** |     |     |      |      |      |      |
| PW                 | 0.46** | -0.02ns | -0.04ns | 0.14ns | 0.46** | 0.38** |     |      |      |      |      |
| LW                 | 0.13ns | 0.12ns | 0.42** | 0.50** | 0.60** | 0.38** | 0.13ns |     |      |      |      |
| BBgs               | 0.27ns | 0.44** | 0.25ns | 0.46** | 0.74** | 0.46** | 0.17ns | 0.63** |      |      |      |
| JlBt               | 0.04ns | -0.01ns | -0.40** | -0.17ns | 0.14ns | 0.23ns | -0.17ns | 0.02ns | 0.29* |      |      |
| Brix               | 0.40** | -0.19ns | -0.44** | -0.32* | 0.19ns | 0.25ns | 0.08ns | -0.24ns | 0.03ns | 0.49** |      |
| EA                 | 0.51** | -0.10ns | -0.46** | -0.32* | 0.30* | 0.35* | 0.16ns | -0.20ns | 0.08ns | 0.47** | 0.91** |

JV=juice volume, PH=plant height, SD=stalk diameter, JN=node number, TBW=total biomass, SW=stalk weight, PW=panicle weight, LW=leaves weight, BBgs=bagasse weight, NS=number of stalk, EA=ethyl alcohol

3. 4. Conclusions

Conclusion of the study showed that plant population was high significantly affect to stalk weight, total biomass yield, leaf weight, and also significantly affect bagass weight and juice volume. Varieties were high significantly different in plant height, juice volume, and number of nodes. Super 1 variety on population at 166,667 plants/ha (P1) was obtained the highest juice volume (19,445 l Ha⁻¹), meanwhile the highest brix value obtained from Numbu at the same plants population. Furthermore juice volume had significant correlation with biomass weight at the r=0.73. Based on ethanol production, Super 2 and Numbu had the highest volume at 83,333 plants/ha density (P3) and Super 1
at 166,667 plants/ha density with the ethanol volume were 827.68 l/ha, 1116.50 l/ha and 993.62 l/ha respectively.

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