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# Effects of invigoration and spacing on growth and seed production of four bambara groundnut (*Vigna subterranea* (L) Verdc) Landraces

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**Key words:** Canopy, Hydropriming, Local landrace, Matriconditioning, *Rhizobium* sp.

**Abstract**

Low production of bambara groundnut in Indonesia is due to low quality seeds and the use of less optimal cultivation technology. Objective of the research was to obtain information on the effects of invigoration and spacing on the growth and seed production of four of bambara groundnut landraces, namely Sumedang, Sukabumi, Tasikmalaya, and Gresik. Field experiment was conducted from November 2015 to June 2016 at Dramaga, Bogor and seed processing laboratory. The experiment utilized three replicate split plot design. Invigoration was the main plot that comprised of three levels, i.e without treatment, matriconditioning + *Rhizobium* sp., and hydropriming. Sub plot was the spacing that comprises of three levels, such as 40 x 10cm, 50 x 20cm, and 60 x 25cm. Result showed that invigoration increased the emergence field of four landraces, but did not increase plant height in all landraces. The spacing of 40 x 10cm increased plant height for Landrace Sumedang, Sukabumi and Tasikmalaya. Hydropriming increased the canopy diameter on the Sumedang and Tasikmalaya and the spacing of 60 x 25cm increased the canopy diameter for all landraces. Seeds without and with invigoration at a spacing of 60 x 25cm gave the highest yield of DW pods and DW pods per plot for all landraces. Invigoration with hydropriming at a spacing of 50 x 20cm and 60 x 25cm increased yield for all landraces. Seed germination was not affected by all invigoration and differences in spacing.

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**Introduction**

Period between the seed planted and the emergence of germination is one of critical periods in life cycle of plant, in which the seeds may face diverse environmental conditions to grow that highly affect the emergence of germinate and vigor of the germinate. Seeds, which are planted in marginal environment, have a potential to face higher environmental stress and may cause the seeds having some difficulties to germinate (Arief and Koes, 2010). Bambara groundnut has hard shell, so that it is impermeable (Berchie *et al.* 2010). Sinefu *et al.* (2011) reported that bambara groundnut seed germinations are frequently indefinite, variable, and slow. However, with such characteristics along with not uniform germination, the bambara groundnut seeds still will germinate within 21 days after planting in the field, but unfortunately, it will have an effect on flowering time, pod formation, and ripening (Sesay and Yarmah, 1996).

Invigoration is treating the seeds pre-planting by balancing potential seed water to stimulate metabolism activity in seeds, so that they will be ready to germinate, but important structures of the embryo, such as radicle, has not emerged yet (Khan 1992; Ilyas 2015). According to Nurmauli and Nurmiaty (2010), there are 3 methods of invigoration namely, hydration-dehydration, osmoconditioning/ hydropriming and matriconditioning. Hydropriming is soaking the seeds in water before planted. Water could soften the shell, reactivate the enzyme, transport the metabolites, and enable the entrance of oxygen (Widajati *et al.* 2013). Nurmauli and Nurmiaty (2010) suggested that soaking the soybean seeds produced higher percentages of seed emergence, accelerated the seeds to grow, produced plant height, length of hypocotyls, length of root, dry weight of root, and dry weight of normal germinate, which were higher than the control. According to Ilyas and Sopian (2013), matriconditioning and matriconditioning plus *Rhizobium* sp. in bambaragroundnut seeds are effective in increasing viability and dry weight of normal germinate, as well as the vigor (acceleration to grow and vigor index) in comparison with no invigoration. Matriconditioning plus *Rhizobium* sp. also increase plant height and yield of bambara groundnut (numbers of pod per plant and fresh weight of pods per plot) in comparison with no invigoration.

Bambara groundnut is not the main crop in Indonesia, so that optimal standard of spacing has not been applied in its seed production. Information about optimal spacing is highly required for seed production, particularly that in relation to the canopy type of bambara groundnut, which is varied from spreading, semi-bunch, to bunch type. Spacing of bambara groundnut in Africa is different from one area to another. Mkandiwire and Sibuga (2002) reported that spacing, which is usually applied in Tanzania is 30cm x 30cm, while in West Africa, the spacing is 60cm x 30cm.

Objective of the research was to obtain information about the effect of invigoration and spacing on the growth and seed production of four bambara groundnut in Indonesia, namely Sumedang, Sukabumi, Tasikmalaya, and Gresik landraces.

**Materials and methods**

Field experiment was conducted from November 2015 to April 2016 at Kampung Jawa Village, Dramaga, Bogor Regency, and continued at the Leuwikopo seed processing laboratory in IPB since April to June 2016. The experiment field location was at altitude 207 m asl (above sea level), and monthly rainfalls range between 415 mm and 673.2 mm, average monthly humidity ranged between 83% and 89%, and average monthly temperature ranged between 25.7$^{o}$C and 26.7$^{o}$C (BMKG, 2016).

The seeds used were collected from bambara groundnut's farmers at several villages, namely Situraja Sumedang, Jampang Kulon Sukabumi, Tasikmalaya, and Gresik, which were harvested between April and June 2015. Before being planted, the seeds were kept in seed storage room at $\pm$20$^{o}$C and RH$\pm$60%.

The experiment utilized a three replication split plot design. Invigoration was the main plot, which comprised of three levels, i.e without treatment (I0), matriconditioning

+ *Rhizobium* sp. (I1) and hydropriming (I2). Sub plot was spacing, which included three levels, i.e 40cm x 10cm (P1), 50cm x 20cm (P2), and 60cm x 25cm (P3). Each combination of the treatment has three replications, so that 108 units of experiments were utilized, with the plot size was 3m x 3m.

Matriconditioning + *Rhizobium* sp. was applied pre-planting by ratio 5:3:3:0.03 (seed: charcoal: water :*Rhizobium* sp.). The seeds were stirred in the mixture, and then kept for 3 days at 25°C, however, stirring must be done everyday (Ilyas and Sopian, 2013). Hydropriming was done by soaking the seeds for 24 hours at 28°C, and then the seeds were air-dried for 3 hours before planted (Safiatou 2012).

One seed was put in each planting hole in accordance with spacing. The plant was nurtured by controlling pest and diseases, weeds, and water conditioning started from planting to harvest time. Harvest time was conducted at ripening phase as marked by hard brown pods, and then it was followed by cleaning, drying, sorting, and shelling the pods. Soil analysis was done before planting. Variables of the observed growth included viability (field emergence), which was counted at 10 days after planting; plant height, which was measured from ground surface to the highest shoot tip from 2WAP (weeks after planting) to 10WAP; canopy width was measured from the outer part of the canopy at 6WAP, 8WAP, and 10WAP.

Variables of the observed-yield component include dry weight of pods per plant, which were taken from five sampled plants of each experimental plot dry weight of pods per plot (sun-dried for ± 2 weeks). Data of the experimental results were analyzed using F-test, and if the given treatment had significant effect, it would be followed by Duncan Multiple Range Test (DMRT) at level α = 0.05.

**Results and discussions**

*Growth Variable*

Invigoration by applying matriconditioning + *Rhizobium* sp. (I1) and hydropriming (I2) had significant effect in increasing viability of bambara groundnut seed of Sumedang, Sukabumi, Tasikmalaya, and Gresik landraces (Table 1). The seeds, without invigoration (I0), had not grown by the 10th day after planting.

**Table 1.** Effect of invigoration treatment on viability (%) of bambara groundnut at 10 days after planting.

| Treatment | Landrace | | | |
|---|---|---|---|---|
| | Sumedang | Sukabumi | Tasikmalaya | Gresik |
| I0 | 64.08c | 53.83b | 43.81b | 71.79b |
| I1 | 88.68a | 89.91a | 88.73a | 89.14a |
| I2 | 83.07b | 87.04a | 85.83a | 87.06a |
| CV (%) | 1.79 | 6.41 | 6.87 | 0.51 |

Description: numbers followed by the same letter in the same column show significant difference on DMRT test at level 5%. I0 (without invigoration); I1 (matriconditioning+*Rhizobium* sp.); I2 (hydropriming)

The treatment of matriconditioning + *Rhizobium* sp or hydropriming have the same effectiveness to increase bambara groundnut germination. Bambara groundnut has a hard seed skin that makes it difficult for water to enter into the seeds, with the treatment of matriconditioning + *Rhizobium* sp or hydropriming, the seed coat becomes soft and ready to fill water so that the seeds are ready to germinate after planting in the field. Seeds that germinate faster will experience less environmental stress so that the plant is expected to `be better in its growth. Invigoration is more effective on seeds planted on dry land or experiencing water stress, this is in accordance with the results of the study of Modi (2013) pre-hydration before planting accelerates the appearance of sprouts, growth and response to lack of water. Invigoration can be interpreted as a process of increasing the speed of growth of bambara groundnut seeds, so that invigoration of seeds can reduce the influence of environmental stress.

Widajati *et al.* (2013) stated that seed invigoration increased viability. Imbibition process is the initial stage of germination, in which water permeates into the seed to activate enzymes in it. Functions of these enzymes are to increase the respiration process, which is required in embryo initiation from the crack of seed coat till the emergence of radical that penetrate the seed coat. Invigoration affected the plant height during early growth (2WAP) in all landraces (Sumedang, Sukabumi, Tasikmalaya, Gresik) (Table 2). This was because invigoration

increased percentage of viability in early cultivation (Table 1), where the seeds germinated earlier and more uniform in comparison with the seeds without invigoration at 8WAP, invigoration did not affect plant height, except in Tasikmalaya landrace. However, at 10WAP, invigoration affected the plant height of Gresik landrace only (Table 2).

**Table 2.** Effect of invigoration and spacing on plant height (cm) of bambara groundnut in Sumedang, Sukabumi, Tasikmalaya, and Gresik landraces.

| Landrace | Treatment | 2WAP | 8WAP | 10WAP |
|---|---|---|---|---|
| Sumedang | | | Invigoration | |
| | Io | 16.34b | 50.31 | 45.19 |
| | I1 | 19.05a | 51.33 | 45.56 |
| | I2 | 17.33b | 51.46 | 45.44 |
| | Mean | - | 51.03 | 45.39 |
| | | | Spacing | |
| | P1 | 17.88a | 53.08a | 47.79a |
| | P2 | 17.75a | 51.13ab | 44.74b |
| | P3 | 17.11b | 48.89b | 43.66b |
| | Mean | - | - | - |
| | CV(%) | 3.36 | 6.05 | 2.35 |
| Sukabumi | | | Invigoration | |
| | Io | 14.28b | 42.66 | 38.27 |
| | I1 | 17.85a | 44.11 | 39.51 |
| | I2 | 16.01ab | 43.86 | 39.43 |
| | Mean | - | 43.54 | 39.07 |
| | | | Spacing | |
| | P1 | 15.74 | 45.42a | 39.69a |
| | P2 | 16.95 | 42.13b | 39.71a |
| | P3 | 15.45 | 43.07b | 37.81b |
| | Mean | 16.05 | - | - |
| | CV (%) | 13.66 | 4.71 | 4.41 |
| Tasikmalaya | | | Invigoration | |
| | Io | 13.35b | 44.49b | 39.74 |
| | I1 | 16.39a | 46.90a | 39.00 |
| | I2 | 15.34ab | 46.03ab | 39.51 |
| | Mean | - | - | 39.42 |
| | | | Spacing | |
| | P1 | 15.29 | 49.38a | 40.14 |
| | P2 | 14.96 | 45.18b | 39.03 |
| | P3 | 14.84 | 42.87b | 39.08 |
| | Mean | 15.03 | - | 39.42 |
| | CV (%) | 6.39 | 5.76 | 3.59 |
| Gresik | | | Invigoration | |
| | Io | 12.94b | 41.07 | 36.33a |
| | I1 | 14.33a | 41.14 | 35.79ab |
| | I2 | 13.98a | 40.58 | 35.36b |
| | Mean | - | 40.93 | - |
| | | | Spacing | |
| | P1 | 13.91 | 43.41a | 36.57a |
| | P2 | 13.82 | 40.42b | 36.13ab |
| | P3 | 13.51 | 38.96b | 34.78b |
| | Mean | 13.75 | - | - |
| | CV (%) | 5.97 | 4.38 | 3.74 |

Description: numbers followed by the same letter in the same column show significant difference in DMRT test 5%. Io (without invigoration); I1 (matriconditioning+*Rizobium* sp.); I2 (hydropriming); P1 (40cm x10cm); P2 (50cm x20cm); P3 (60cm x25cm), WAP (week after planting).

In Sumedang landrace, I1 produced the highest plant (19.05cm) in comparison with Io (16.34cm) and I2 (17.33cm) at 2WAP. I1 Sukabumi landrace produced the highest plant (17.85cm) at 2WAP, even though it did not show significant difference with I2 (16.01cm). At 8WAP and 10WAP, invigoration did not show any difference on plant height. At 2 and 8WAP, I1 produced the highest plants in Tasikmalaya landrace with the height 16.39cm and 46.90cm, respectively, but it did not show any difference with I2.I1 on Gresik landrace produced the highest plant at 2WAP for about 14.33cm, but it did not show significant difference with I2 (13.98cm). On the contrary, at 10WAP, Io Gresik landrace produced the highest plant than other (36.33cm) (Table 2).

Invigoration I1 (matriconditioning + *Rhizobium* sp.) produced the highest plants in all landraces (Table 2). According to Ilyas and Sopian (2013), matriconditioning + *Rhizobium* sp. increased plant height of bambara groundnut in comparison with other invigoration treatments and the control. Sari and Prayudyaningsih (2015) reported that *Rhizobium* sp. assists the plant to bind free N in the atmosphere (N2) to become ammonia (NH3) in order to produce nitrogen compounds, which was used for the plant to grow and develop. Different spacing did not have significant effect on plant height in early growth (2WAP), because the overlapping canopies had not formed yet, so that the plants get optimal light. Sumedang landrace, the spacing P1 (40cm x10cm) and P2 (50cm x20cm), did not show significant difference, while P3 (60cm x25cm) produced the shortest plants at 2WAP and 8WAP in the plant height.

Sukabumi landrace, different spacing did not have significant effect on plant height at 2WAP. However, at 8WAP, P1 produced the highest plant (45.42cm) in comparison with the P2 and P3, while at 10WAP, P3 produced the shortest plant (37.81cm). Tasikmalaya landrace was affected by spacing at 8WAP, in which PI produced the highest plant (49.38cm) in comparison with P2 and P3. Gresik landrace, P1 produces the highest plant at8WAP (43.41cm) and 10WAP (36.57cm) (Table 2).

P1 (40cm x10cm) as the narrowest spacing generally produced the highest plant, while P3 (60cm x25cm), which had wider spacing, produced shorter plant (Table 2). It has been established that bambara groundnut is a creeping herb and if the growing space is wide enough, the plant tends to grow widened, so that the plant becomes shorter and diameter of the canopy become wider (Safiatou, 2012).

Invigoration (I1 and I2) affected the canopy diameter of Sumedang and Tasikmalaya landraces at 8WAP and 10WAP. Invigoration only affected at canopy diameter of Gresik landrace at 8WAP. In Sumedang landrace, I1 produced the largest diameter of canopy (75.09cm) although it was not different from I2 (74.54cm) at 8WAP. Meanwhile at 10WAP, I2 produced the largest diameter of canopy (62.56cm), even though it was not different from I1 (60.01cm) (Table 3).

Invigoration did not affect the canopy diameter of Sukabumi landrace. Tasikmalaya landrace, I1 produced the largest diameter of canopy, although it was not different from I2 at 8 and 10WAP. At 8WAP, Gresik landrace produced the largest diameter of canopy in I2 (57.11cm), although it was not different from I1 (54.04cm). At 10WAP, the canopy diameter of Gresik landrace did not show any difference among treatments of invigoration (Table 3).

Invigoration (I1 and I2) produced wider diameter of canopy than without invigoration. It was due to that seed invigoration was effective to increase vegetative growth including the canopy growth. The invigorated seeds germinated faster and more uniform, so that the vegetative growth grew better. Seed metabolism during invigoration triggered the acceleration of α-amylase enzyme activity (germination enzyme). Fitriesa (2015) suggested that the invigorated bambara groundnut had wider diameter of canopy than without invigoration. According to Afzal *et al.* (2002), matriconditioning increased germination ability, reduced T50, increased root length, and diameter of canopy in hybrid corn.

**Table 3.** Effect of invigoration and spacing on diameter of canopy (cm) in bambara groundnut of Sumedang, Sukabumi, Tasikmalaya, and Gresik landraces at 8WAP and 10WAP.

| Landrace | Treatment | Age of Plant | |
|---|---|---|---|
| | | 8WAP | 10WAP |
| Sumedang | | Invigoration | |
| | I0 | 69.92b | 57.93b |
| | I1 | 75.09a | 60.01ab |
| | I2 | 74.54a | 62.56a |
| | Mean | - | - |
| | | Spacing | |
| | P1 | 69.61b | 55.57c |
| | P2 | 74.10ab | 58.81b |
| | P3 | 75.844a | 66.12a |
| | Mean | - | - |
| | CV (%) | 7.094 | 5.021 |
| Sukabumi | | Invigoration | |
| | I0 | 60.81 | 56.56 |
| | I1 | 63.66 | 56.12 |
| | I2 | 64.77 | 57.93 |
| | Mean | 63.08 | 56.87 |
| | | Spacing | |
| | P1 | 58.06b | 55.11b |
| | P2 | 63.72a | 56.12a |
| | P3 | 67.46a | 56.12a |
| | Mean | - | - |
| | CV (%) | 6.15 | 5.22 |
| Tasikmalaya | | Invigoration | |
| | I0 | 56.93b | 54.73b |
| | I1 | 62.93a | 59.04a |
| | I2 | 61.73ab | 59.50a |
| | Mean | - | - |
| | | Spacing | |
| | P1 | 56.01b | 56.15b |
| | P2 | 59.92b | 57.31b |
| | P3 | 65.67a | 59.81a |
| | Mean | - | - |
| | CV (%) | 6.47 | 3.59 |
| Gresik | | Invigoration | |
| | I0 | 48.06b | 56.51 |
| | I1 | 54.04a | 56.53 |
| | I2 | 57.11a | 56.58 |
| | Mean | - | 56.54 |
| | | Spacing | |
| | P1 | 50.26b | 55.84b |
| | P2 | 53.72ab | 56.18ab |
| | P3 | 55.23a | 57.60a |
| | Mean | - | - |
| | CV (%) | 6.70 | 2.59 |

Description: numbers followed by the same column show significant difference in DMRT test 5%. I0 (without invigoration); I1 (matriconditioning+ *Rizobium* sp.); I2 (hydropriming); P1 (40cm x10cm); P2 (50cm x20cm); P3 (60cm x25cm), WAP (week after planting).

Spacing affects diameter of canopy in Sumedang, Sukabumi, Tasikmalaya, and Gresik landraces. In Sumedang landrace, P3 produced the widest diameter of canopy (75.84cm), but it did not show any difference with P2 (74.10cm) at 8WAP.

Meanwhile, at10WAP, P3 produced the widest diameter of canopy, 66.12cm. In Tasikmalaya landrace, P3 at 8 and 10WAP produced the widest diameter of canopy, 65.67cm and 59.81cm, respectively, in comparison with P1 and P2 (Table 3).

P3 produced the largest diameter of canopy, particularly in Sumedang and Tasikmalaya landraces, which had spreading type due to the plant had enough space for the canopy growth. P1 was the narrowest spacing that produced smaller diameter of canopy and higher plant (Table 2). According to Safiatou (2012), bambara groundnut is a creeping herb and if the growing space is wide enough, the plant tends to grow widened, so that the plant becomes shorter and diameter of the canopy become wider.

In Sukabumi landrace spacing P1produced the smallest canopy than at P2 and P3. However, P3 increased diameter of canopy in Gresik landrace at8WAP (55.23cm) and 10WAP (57.60cm) (Table 3). Sukabumi landrace had semi-bunch type of canopy, while Gresik landrace has bunch type of canopy. P3 produced diameter of canopy, which was not different from P2, and it was assumed that P2 (50cm x20cm) had provided sufficient space for the plant to form canopy. The result conforms to the finding by Alhassan *et al*. (2012), which reported that bambara groundnut with bunch type did not have significant difference on the diameter of canopy in population of 100000 plantha$^{-1}$ and 50000 plantha$^{-1}$. Spacing that conforms to canopy types will produce optimal growth of canopy.

According to Juwita (2012), diameter of bambara groundnut's canopy has positive correlation with the yield, so that variable of the canopy diameter could be used as one of important factor to increase production. At 8WAP, development of the canopy reached the peak due to the plant starting to enter generative phase at 40-50 DAP.

*Variable of Yield*

Invigoration may not affect dry weight (DW) of pods per plant in Sumedang landrace. Dry weight (DW) of pods per plant, P2 was higher (13.95g) than other spacing, although it was not significantly different from P3 (12.39g) (Table 4). The spacing of 50cm x 20cm (P2) and 60cm x 25cm (P3) produced DW pods per plant that were not significantly different, but higher than the planting distance of 40cmx10cm (P1).

**Table 4.** Effect of invigoration and spacing on dry weight (DW) of pods per plant of Sumedang landrace.

| Treatment | DW pod/plant (g) |
|---|---|
| Invigoration | |
| I0 | 13.72 |
| I1 | 7.18 |
| I2 | 12.64 |
| Mean | 11.18 |
| Spacing | |
| P1 | 7.21b |
| P2 | 13.95a |
| P3 | 12.39a |
| Mean | - |
| CV (%) | 15.85 |

Description: numbers followed by the same column show significant difference in DMRT test 5%. I0 (without invigoration); I1 (matriconditioning +*Rizobium* sp.); I2 (hydropriming); P1 (40cm x10cm); P2 (50cm x20cm); P3 (60cm x25cm).

Interaction between invigoration and spacing in Sumedang landrace showed significant results on DW of pods per plot. Sumedang landrace showed an inconsistency in response to treatment (Table 5), it was suspected that Sumedang landrace had not been genetically stable and had high diversity. The data showed that the best DW of pods without invigation (I0) was obtained from a combination of treatment I0P2 (26.83g) and I0P3 (22.50g). Different results indicated by seed treatment with hydropriming (I2) showed the best results in a combination of I2P2 (21.69g) and I2P3 (23.59g). Based on these results it could be seen that invigoration had an effect only at a wider spacing (P3). Sumedang landrace had a type of spread canopy spread, a large spacing is needed to support its growth. Based on the dry weight of pods, both plant and per plot, Sumedang landrace showed the lowest pod production compared to other plants. This was different from the results of the bambara groundnut farmers in Sumedang which on average could produce 18.77qu.ha-1 dried pods. Sumedang landrace was thought to be an area with location-specific characteristics, due to only producing maximally in its area of origin.

**Table 5.** Interaction between invigoration and spacing on dry weight of pods per plot in Sumedang landrace.

| Treatment | DW pod per plot (g) | | |
|---|---|---|---|
| | P1 | P2 | P3 |
| I0 | 11.58f | 26.83a | 22.50ac |
| I1 | 18.04cd | 16.54de | 20.19bd |
| I2 | 13.32ef | 21.69bc | 23.59ab |
| CV (%) | | 14.52 | |

Description: numbers followed by the same column show significant difference in DMRT test 5%.I0 (without invigoration); I1 (matriconditioning + *Rizobium* sp.); I2 (hydropriming); P1 (40cm x10cm); P2 (50cm x20cm); P3 (60cm x25cm).

Invigoration did not provide an increase in the Sukabumi landraces pods, while the spacing affected the DW pod. The I0 treatment gave the highest pod yield per pod on the Sukabumi landraces (1623.6g) when compared to treatment I1 (1232.9g) and I2 (1282.8g). The P2 and P3 treatments in the Sukabumi DW landraces (1551.73g and 1542.21g) were higher than in treatment P1 (Table 6).

**Table 6.** Effects of invigoration and spacing on dry weight of pods per plot in Sukabumi landrace.

| Treatment Invigoration | DW pod/plot (g) |
|---|---|
| I0 | 1623.6a |
| I1 | 1232.9b |
| I2 | 1282.8b |
| Mean | - |
| Spacing | |
| P1 | 1045.34b |
| P2 | 1551.73a |
| P3 | 1542.21a |
| Mean | - |
| CV (%) | 12.96 |

Description: numbers followed by the same letter in the same column show significant difference in DMRT test 5%. I0 (without invigoration); I1 (matriconditioning + *Rizobium* sp.); I2 (hydropriming); P1 (40cm x 10cm); P2 (50cm x 20cm); P3 (60cm x 25cm).

Interaction between invigoration and spacing in Sukabumi landrace showed significant result DW of pods per plant (Tabel 7), but it could be seen that there was a discrepancy in response to the treatment. The data showed that the best dry weight of pods without invigoration (I0) was obtained from a combination of treatment I0P2 (37.06g) and I0P3 (31.70g), whereas hydropriming (I2) showed the best results in combination I2P3 (53.28g).

**Table 7.** Interaction between invigoration and spacing on dry weight of pods per plant and per plot in Sukabumi landrace.

| Treatment | DW pod per plant (g) | | |
|---|---|---|---|
| | P1 | P2 | P3 |
| I0 | 14.62d | 37.06bc | 31.70c |
| I1 | 21.25d | 44.22b | 37.82bc |
| I2 | 21.27d | 35.54c | 53.28a |
| CV (%) | | 12.67 | |

Description: numbers followed by the same column show significant difference in DMRT test 5%. I0 (without invigoration); I1 (matriconditioning+ *Rizobium* sp.); I2 (hydropriming); P1 (40cm x 10cm); P2 (50cm x 20cm); P3 (60cm x 25cm).

**Table 8.** Effect of invigoration and spacing on dry weight of pods per plant and per plot in Tasikmalaya landrace.

| Treatment Invigoration | DW pod/plant | DW pod/plot |
|---|---|---|
| I0 | 24.69 | 953.4 |
| I1 | 26.27 | 1309.7 |
| I2 | 21.58 | 1174.5 |
| Mean | 24.18 | 1145.87 |
| Spacing | | |
| P1 | 14.62b | 898.9 |
| P2 | 21.87b | 1107.6 |
| P3 | 36.05a | 1431.1 |
| Mean | - | 1145.87 |
| CV (%) | 17.60 | 18.21 |

Description: numbers followed by the same column show significant difference in DMRT test 5%. I0 (without invigoration); I1 (matriconditioning+ *Rizobium* sp.); I2 (hydropriming); P1 (40cm x10cm); P2 (50cm x 20cm); P3 (60cm x 25cm).

Invigoration did not affect on DW of pods per plant, as well as per plot in Tasikmalaya landrace. Spacing affected DW of pods per plant, but not for DW of pods per plot (Tabel 8). P3 in Tasikmalaya landrace produced heavier DW of pods per plant (36.05g).

The increased yield of DW of pods per plant was presumed due to that Tasikmalaya landrace had a spreading canopy type, which grew better with wide spacing, so that the pod filling was optimum.

**Table 9.** Interaction between invigoration and spacing on dry weight of pods per plant and per plot in Gresik landrace.

| Treatment | DW pod per plant (g) | | | DW pod per plot (g) | | |
|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P1 | P2 | P3 |
| I0 | 12.32d | 25.29c | 39.21ab | 399.53e | 1151.52c | 2157.81a |
| I1 | 12.42d | 8.94d | 32.83b | 454.51e | 755.19d | 982.70cd |
| I2 | 10.89d | 34.15b | 41.32a | 454.49e | 2174.12a | 1598.48b |
| CV (%) | | 17.57 | | | 10.72 | |

Description: numbers followed by the same column show significant difference in DMRT test 5%. I0 (without invigoration); I1 (matriconditioning + *Rizobium* sp.); I2 (hydropriming); P1 (40cm x 10cm); P2 (50cm x 20cm); P3 (60cm x 25cm).

Interaction between invigoration and spacing in Gresik landrace showed significant result on dry weight of pods per plant, as well as per plot (Tabel 9). DW plant pods with treatment I0 gave the best results obtained from a combination of I0P3 (39.21g). Gresik landrace with treatment I2 produced the best DW on a combination of treatment I2P2 (34.15g) and I2P3 (41.32g).

The results of the observation on the pod DW variable per plot showed that with the I0 treatment the best results were obtained from a combination of I0P3 (2157.8g). Whereas the best treatment of DW pod per plot was obtained from a combination of I2P2 treatments (2174g). Gresik landrace with the growth type of bunch canopy, produced DW pods per largest plant at the widest spacing of 60cm x 25cm (P3), while the yield of DW pods per plot was greater at a spacing of 50cm x 20cm (P2). This was because the number of plants harvested in P2 plot is more than the number of plants in P3.

Invigoration has an effect on the vegetative phase, but did not have an effect on the narrow spacing of the results of the four bambara groundnut varieties. The growth of bambara groundnut in the vegetative phase is very good, has a large and lush canopy diameter, causing competition in individual plants in dividing the assimilate results into the vegetative and generative phases. The number of peanut pods produced is less due to competition in plants in allocating assimilates during the vegetative and generative phases (Mas'udah 2008).

Spacing of P2 (50cm x 20cm) and P3 (60cm x 25cm) gave greater results than P1 (40cm x 10cm) on all landraces used, although it had a different type of canopy growth that was spread (landraces Sumedang and Tasikmalaya), semi (Sukabumi) and bunch (Gresik). This was in accordance with the results of a study by Hamakareem *et al* (2016) that the spacing of 60cm x 30cm gave better results than the spacing of 50cm x 30cm on peanuts.

Wider spacing produced more branches than narrower spacing, indicating that plants were more vigorous if there was less competition for light and nutrients (El Naim *et al.* 2010). Hidayat (2008) stated that, the closer the spacing could reduce yield on peanut plants, which was caused by a decrease in light received by plants due to mutually covering leaves which could cause photosynthetic results for pod formation to be low.

Sumedang landrace which had very good vegetative growth, very leafy leaves but had little pod yield, especially at narrow spacing, this might be due to leaves growing overlapping so that they had a small leaf area index, so even though they had leaves that many but not effective in photosynthesis to produce assimilates which will be used in filling pods. Sumedang landrace had a spread type canopy that requires a wider spacing. Leaves were the main organ producing biomass through photosynthesis.

In order for maximum biomass productivity, the number of leaves and their composition in canopy architecture must be optimal. Plant canopies are very important their role in the process of photosynthesis exceeds individual leaves. This is related to the position of the leaves in the canopy of the plant, the upper part generally gets more light, while the lower part gets less or even irradiation (Oosterhuis *et al.* 1990).

*Seed Quality*

The physiological quality of bambara groundnut seeds is indicated by testing the germination of seeds. Seed quality testing is carried out four weeks after harvest. The germination of the four bambara groundnut landraces is presented in Table 10.

**Table 10.** Effect of invigoration and spacing on seed germination.

| Treatment Invigoration | Sumedang | Gresik | Sukabumi | Tasikmalaya |
|---|---|---|---|---|
| I0 | 63.78 | 83.78 | 85.56 | 73.78 |
| I1 | 61.11 | 84.67 | 83.56 | 72.56 |
| I2 | 67.67 | 84.44 | 86.44 | 70.22 |
| Mean | 64.19 | 84.30 | 85.19 | 72.19 |
| Spacing | | | | |
| P1 | 67.00 | 84.67 | 86.22 | 68.67 |
| P2 | 66.67 | 82.22 | 86.44 | 73.22 |
| P3 | 58.89 | 86.00 | 82.89 | 74.67 |
| Mean | 64.19 | 84.30 | 85.18 | 72.19 |

Description: numbers followed by the same column show significant difference in DMRT test 5%. I0 (without invigoration); I1 (matriconditioning + *Rizobium* sp.); I2 (hydropriming); P1 (40cm x 10cm); P2 (50cm x 20cm); P3 (60cm x 25cm).

The results showed that the invigoration treatment and spacing did not have a significant effect on the germination of the seeds harvested by four bambara groundnut seeds. Seed germination (SG) which only ranges from 64%-86%, probably caused by the seed being tested four weeks after harvesting, it was suspected that bambara groundnut had dormancy after rippening and dormancy had not broken for four weeks. The effect of invigoration was likely not to survive until the variable quality of results, because the quality of seeds produced from seed production in the field was strongly influenced by genetic and environmental factors.

**Conclusions**

1. Invigoration was able to increase the emergence field of four bambara groudnut, but did not increase plant height in all landraces. The spacing of 40cm x 10cm increased plant height for Sumedang, Sukabumi and Tasikmalaya landraces. Hydropriming increased the canopy diameter on the Sumedang and Tasikmalaya landraces and the spacing of 60cm x 25cm increased the canopy diameter for all landraces.
2. Seeds without and with invigoration at a spacing of 60cm x 25cm gave the highest yield of dry weight pods and pods per pod for all landraces. Invigoration with hydropriming at a spacing of 50cm x 20cm and 60cm x 25cm increased yield for all landraces.
3. Seed germination was not affected by invigoration of matriconditioning + Rhizobium sp and hydropriming as well as differences in spacing.

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