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Research Article
Classification of Seed Resistance of Various Genotypes of Sorghum (*Sorghum bicolor* [L.] Moench.) to Weevil (*Sitophilus* sp.) During Storage

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Abstract
Background and Objective: The supply of sorghum seed faces the problem of a weevil pest (*Sitophilus* sp.) during storage. The objective of this experiment was to determine the seed resistance of various genotypes of sorghum to weevils during storage, both in high and low temperature was conducted using a "choice method" based on painter theory. **Materials and Methods:** Three kinds of "choice method" (with the challenge, no challenge and control) were used to evaluate seed resistance to weevil of 34 genotypes of sorghum in Indonesia. This two-factor experiment (genotype and kind of method) was applied in a randomized complete block design with three replications. **Results:** There were differences in the weevil numbers in the three with "choice methods" and on seeds resistance to weevil among sorghum genotypes. There was significantly correlated between the weevil numbers and the percentage of damaged seeds with $r = 0.98$ ($p<0.01$) and with the percentage of intact seeds with $r = 0.57$ ($p<0.01$). Using a median value with 95% confidence interval, the 34 genotypes of sorghum could be classified into three groups of seed resistance to the weevil, which was high (11 genotypes), moderate (12 genotypes) and low (11 genotypes). **Conclusion:** The seed resistance of various genotypes of sorghum in Indonesia to weevil was different. The most vulnerable genotype (Numbu) was three times preferred by weevil compared to that the most resistant genotype (Samurai-1). Seed resistance to weevil could increased by reducing the temperature of storage room.

Key words: Genotype, seed resistance, sorghum, weevil, choice method

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Sorghum crop [*Sorghum bicolor* (L.) Moench.] are the potential crop to be developed in Indonesia. Sorghum is a tropical C-4 plant which can produce seeds 3-4 t ha^{-1}, stover 17-21 t ha^{-1} and sap that can be made ethanol into 3000 L ha^{-1} [1] or even reached 3900-5700 L ha^{-1} [2]. According to Barcelos *et al.*[3], ethanol yield from sorghum grain could be 5 fold (450 L t^{-1}) higher than those from sugar cane (80 L t^{-1}). In its development, the supply of sorghum seeds would face the constraints of weevil pest (*Sitophilus* sp.) which causes seed damage during storage. Weevil becomes a very harmful pest on sorghum seed, either corn weevil (*Sitophilus zeamais* Motsch.)[4,5] or rice weevil (*Sitophilus oryzae* L.)[6-9]. Weevils spread around the world but its development is faster in the warmer climate of tropical areas[10], such as Indonesia. The life cycle of the weevil is shorter at higher ambient temperatures and have higher relative humidity[11].

Some reports suggested that there were several genotypes of sorghum that resistant to weevil[7,8,12]. Resistance to rice weevil (*Sitophilus oryzae* L.) was varied among rice varieties[13] and also resistance to maize weevil (*Sitophlis zeamais* Motsch.) varied among maize genotypes[14]. In addition to the nutritional content, the physical properties of seed grain influences the weevil preference to sorghum seeds such as seed size and weevil more prefer to bigger size of seed than the smaller one[15].

The problem that arises was what genotypes of sorghum in Indonesia whose seeds having high, moderate or low resistance to weevil during storage. There were several variables for measuring the seed resistance to the weevil, namely the percentage of seed loss or loss of seed weight, number of weevil in seed lot, developmental period of weevil[16] and seed damage[6,12]. During storage, other than experiencing physiological deterioration mainly due to storage length and storage environment such as temperature and relative humidity, seeds can also be damaged by storage pests such as weevil. It was stated by Fourar-Belaifa *et al.*[17] as an interaction between physiological and physical factors of seed deterioration. How to classify sorghum genotypes in Indonesia whose seeds having high, moderate and low resistance to weevil during storage?

The objective of this experiment was to determine the seed resistance of various sorghum genotypes to weevil during storage. This experiment was done in high temperature (26.9±0.7°C) and in low-temperature storage (18.1±1.4°C). There would be different seed resistance to weevil among sorghum genotypes.

MATERIALS AND METHODS

Seed preparation: The sorghum seeds of 34 genotypes were used in this experiment, comprising 23 genotypes produced by plant breeding program of the National Atomic Energy Agency (BATAN), 3 genotypes produced by the International Center Research in Semi-Arid Tropic (ICRISAT) India and 8 genotypes produced by the Indonesia Ministry of Agriculture. The genotypes obtained from BATAN were GHP-1, GHP-3, GHP-5, GHP-11, GHP-29, GHP-33, GH-1, GH-2, GH-3, GH-4, GH-5, GH-6, GH-7, GH-8, GH-9, GH-10, GH-11, GH-12, GH-13, GH-14, Pahat, Samurai-1 and Samurai-2. The genotypes produced by ICRISAT India were P/F-5-193-C, P/F-10-90-A and CYMMIT. The genotypes produced by the Indonesia Ministry of Agriculture were Mandau, Kawali, P/W-WHP, Talaga Bodas, UPCA, Numbu, Super-1 and Super-2. All genotypes of sorghum were cultivated with the same method in a land at the Pekon Bumiaji, Marhaen Village, Sub-district of Anak Tuha, Regency of Central Lampung, Province of Lampung, Indonesia during April-July, 2015. The seeds were harvested at the end of July to early August, 2015. After harvesting, the seeds that were still in panicle were dried up to a water content of 9.37±0.43%, then the seeds were knocked out of panicles and cleaned of all non-seed material, so that the seeds were stored at the Laboratory of Seed and Plant Breeding, Faculty of Agriculture, University of Lampung, Indonesia. The storage periods was 6 months (October, 2015 to March, 2016) and during that period the seeds were then used in weevil resistance testing.

Testing of seed resistance to weevil during storage: Testing of seed resistance to weevil various genotypes of sorghum used "choice method" as an opposed to "no choice method" used by Torres *et al.*[18]. It was based on Painter theory[19] that resistance of plants to pest could be created through three ways, namely (a) Non-preference, (b) Antibiosis and (c) Tolerance. Using "choice method", sorghum seed of a non-preference genotype by weevil would get low weevil attacks and it could be categorized as a high seed resistance to weevil and vice versa. Three kinds of choice method used in this experiment were (a) Method-1: No weevil infested in the initial cage and pathway from the initial cage (C) to the seeds in the plastic cup (S) was not bridged and it was called a control, (b) Method-2: 100 weevils infested in the initial cage and pathway (P) from the initial cage (C) to the seed in a plastic cup (S) was bridged and it was called no challenge method and (c) Method-3: 100 weevils infested in the initial cage (C) and pathway (P) from the initial cage (C) to the seed in the plastic cup (S) was not bridged and it was called with challenge method (Fig. 1).

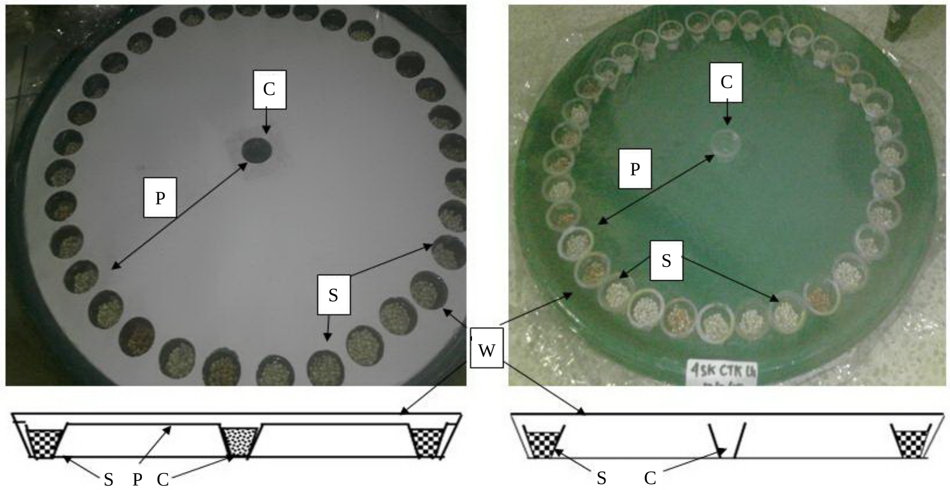

Fig. 1: "Choice method" for seed tolerance test on weevil (*Sitophilus* sp.). Pathway (P) from the initial cage (C) to the seed in the plastic cup (S) with bridge (left) and the pathway from the initial cage (C) to the seed in the plastic cup without a bridge (right), W: Transparent plastic wrap covering trays. Above is test method viewed from the top and below is test method viewed from the side. Right below: was a model of method-1 (no weevil was infested in C) or method-3 (weevil was infested in C). Left below: was a model of method-2 and (weevil was infested in C)

A number of 200 sorghum seeds of each genotype were contained in a 4 mL plastic cup with a mouth diameter of 1.5 cm and a height of 2.5 cm, so resulting in 34 plastic cups. Thirty four cups filled with seeds were arranged on the inside edge of a plastic tray with the diameter of 50 cm (Fig. 1), thus forming a circle. On the circular axle of the 34 plastic cups, an empty plastic cup was placed as an initial cage where weevil pest infested in this test.

Shortly before the tray closed with a plastic wrapper, the cover of an initial cage containing 100 weevils was opened by jabbing a pencil tip on the cage cover, so that the weevils could come out of the cage and moved toward the seeds around it. Then, the plastic wrapper used for covering the tray was attached tightly to the edge of the tray with plastic glue, so there were no more gaps for the weevils to get out from the tray. For aeration, 10 small holes were made on the wrapper plastic of tray cover by inserting the tip of the needle. The seeds in the tray were then kept in storage room, one set of experiment was placed in a low-temperature storage (18.1$\pm$1.4°C) and relative humidity (RH) 50.5$\pm$5.5% and one other set of the experiment was placed in a high-temperature storage (26.9$\pm$0.7°C) and RH 65.2$\pm$9.6%. Physical qualities of seeds were then observed for every 2 months up to 6 months.

Observation: Variables that had been observed were (1) Weevil numbers (WN) existing with seeds in each the cup of each genotype, (2) Percentage of intact seeds (PIS), namely the seeds that were not attacked by weevil and (3) Percentage of damaged seeds (PDS), namely the seeds that were attacked by the weevil.

Weevil numbers, percentage of intact seeds and percentage of damaged seeds: The weevil numbers existing with the seeds (WN) were observed by counting all of the live or dead weevils existing with the seeds in each plastic cup of each genotype. Before they were counted, all plastic cups were covered slowly with duct tape, so the weevils did not run out of the cups. Then, one by one of the cups, weevil numbers was counted. The seeds together with weevils in the cup were poured on the surface of white observation table. Live weevils were firstly made death by pressing them with the index finger and then they were counted. The intact seeds were seeds with no physical damage caused by weevil attacks and also they did not break when they were pressed with pointer finger. The damaged seeds were the seeds with physical damaged caused by weevil attacks or when they seemed to be intact seed, but they were broken when they were pressed with pointer finger. Percentages of intact seeds (PIS) and damaged seeds (PDS) were then made based on 200 grains of seeds contained in the plastic cup.

Experiment design: This experiment was a two factors experiment arranged in randomized complete block design (RCBD), with three blocks as replicates. The first factor was genotype of sorghum (G) consisting of 34 genotypes. The second factor was kind of "choice method" (M) consisting of three methods, namely method-1, method-2 and method-3 as mentioned above. Two sets of experiments were made, one was stored at low temperature and the other one was storage at high temperature.

Statistical analysis: Two-way ANOVA in RCBD with the p = 0.05 was used for analyzing data to see the effects of treatments simultaneously. Homogeneity of variance among treatments and non-additivity of data were tested using Bartlett and Tukey's tests, respectively, that were done before ANOVA.

Medians with 95% confident interval of the data of variables WN, PDS and PIS of 34 genotypes were stated a x_w, x_d and x_i were used to classify the seed resistance to weevils. Seeds containing low weevil number ($WN<x_w$ or $PDS<x_d$ or $PIS>x_i$) were classified as high resistance (H). Seeds containing moderate weevil number ($WN = x_w$, or $PDS = x_d$, or $PIS = x_i$) were classified as moderate resistance (M). Seeds containing high weevil number ($WN>x_w$ or $PDS>x_d$ or $PIS<x_i$) were classified as low resistance (L). Tukey's of honestly significant difference (Tukey's HSD 5% test) was used to compare treatments means of methods. T-student test at 5% was used to compare the seed resistance to weevil between storage under high temperature and under low temperature.

RESULTS

Analysis of variance: Summary of analysis of variance presented in Table 1 showed that the effect of genotype (G) and the testing method (M) were highly significant (p<0.01) on the variables of the weevil number (WN), percentage of intact seeds (PIS) and percentage of damaged seeds (PDS). Interaction effect of the genotype (G) and the method (M) was also highly significant on variable of weevil number (WN) both in low or high-temperature storages, but on variables PDS and PIS, it was highly significant in low-temperature storage only. It meant that the weevil number (WN) existing with the seeds of various genotypes of sorghum varied in the three of test methods, both in the storage room. Therefore, the classification of seed resistance to weevils was made by combining the classification of seed resistance on weevil based on WN, PDS and PIS.

Effects of testing methods and temperature of storage room: The testing methods caused the difference in the WN, PDS and PIS both in low or high temperature storage rooms (Table 2). It showed clearly that seeds occupied by more weevils have less percentage of intact seeds (PIS) and more percentage of damaged seeds (PDS). The temperature of

Table 1: Summary of the results of the analysis of variance effect of genotype (G) and test method (M) on the weevil numbers (WN), percentage of intact seeds (PIS) and percentage of damaged seeds (PDS) in two different storage conditions

	Storage temperature (26.9±0.7°C)			Storage temperature (18.1±1.4°C)		
Variables	G	M	G×M	G	M	G×CM
Weevils number (WN) (unit)	**	**	**	**	**	**
Percentage of intact seeds (PIS)	**	**	NS	**	**	**
Percentage of damaged seed (PDS)	**	**	NS	**	**	**

NS: Non significant at p = 0.05, **Highly significant at p<0.01

Table 2: Weevil numbers (WN) (*Sitophillus* sp.) existing with seeds of each genotype, percentage of intact seeds (PIS) and percentage of damaged seeds (PDS) in storage with high and low of temperature

Methods	WN (unit)	PIS (%)	PDS (%)
A. In high temperature storage room			
Method-1: No weevil invested+no bridge	11.86[a]	59.62[a]	40.38[a]
Method-2: Weevil invested+bridge	13.96[b]	46.77[b]	53.23[b]
Method-3: Weevil invested+no bridge	16.31[c]	46.33[b]	53.77[b]
Average	14.04	50.91	49.12
Tukey's HSD 5%	0.33	2.35	2.34
B. In low temperature storage room			
Method-1: No weevil invested+no bridge	1.38[a]	97.18[a]	2.82[a]
Method-2: Weevil invested+bridge	4.80[b]	95.00[b]	5.06[b]
Method-3: Weevil invested+no bridge	4.96[b]	92.67[c]	7.33[c]
Average	3.71	94.95	5.07
Tukey's HSD 5%	0.47	0.49	0.47
C. Between two temperature storage rooms			
In high temperature storage	14.04[b]	50.90[b]	49.10[b]
In low temperature storage	3.71[a]	94.93[a]	5.07[a]
t-test	31.24	69.40	69.42
p-value	<0.01	<0.01	<0.01

Numbers in the same column followed by the same letter was not significance different according to Tukey's HSD 5%

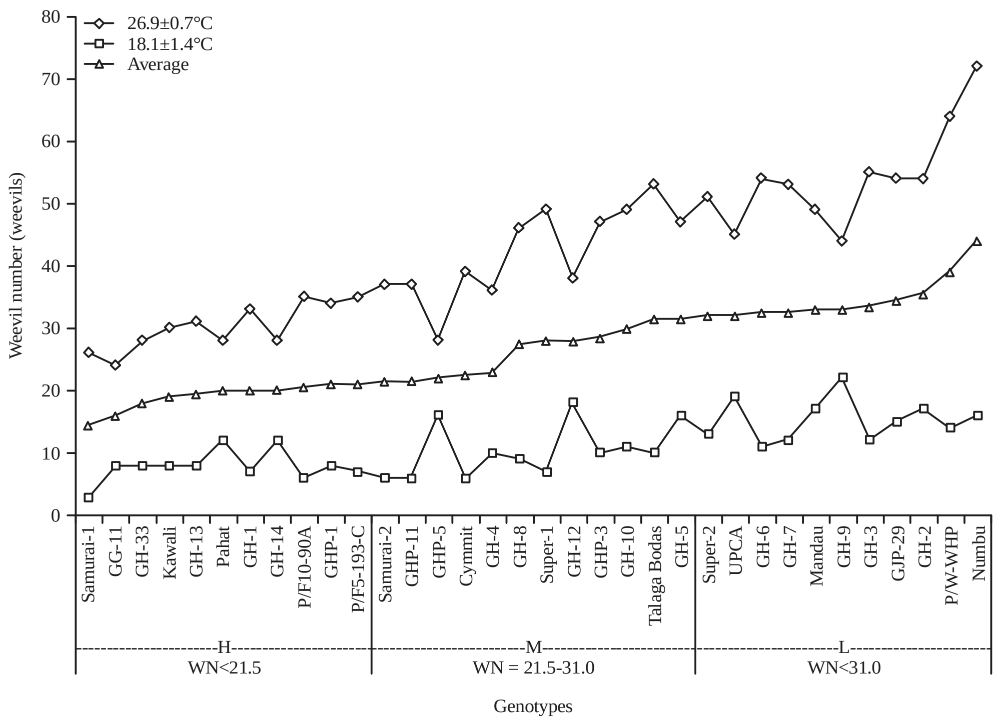

Fig. 2: Relationship between genotypes and weevil numbers (WN), in low temperature storage, in high temperature storage and average. The 34 genotypes could be grouped into high resistance (H), moderate resistance (M) and low resistance (L) to the weevil

storage room influenced in the highly significance of observed variables (PDS, PIS and WN) (Table 2). Therefore, the use of weevil numbers (WN) as a variable indicating level of preference of the weevil to sorghum seeds was exact. The seeds of a sorghum genotype inhabited by more weevils showed more preferred by the weevil, thus it experienced larger weevil attacks and it expressed as having a lower resistance on weevil than the seeds of a sorghum genotype those were inhabited by the fewer weevils. The weevil numbers together with the seeds was negatively correlated with the percentage of intact seeds and positively correlated with the percentage of the damaged seeds. It was occurred in both high and low-temperature storages.

Effect of genotypes on weevil numbers (WN): The effect of genotype factor on weevil numbers (WN) was highly significance ($p<0.01$), both in low or high temperature storage rooms (Fig. 1). The relationships between genotypes and weevil numbers were presented in Fig. 2. Using value of median with confidence interval of 95%, seed resistance to weevil of the 34 genotypes could be grouped into (a) Low resistance genotypes, (b) Moderate resistance genotypes and (c) High resistance genotypes (Table 3). The low resistance genotypes consisted of Numbu, P/W-WHP, GH-2, GHP-29, GH-3, GH-9, Mandau, GH-7, GH-6, UPCA and Super-2. The moderate resistance genotypes consisted of GH-5, Talagabodas, GH-10, GHP-3, GH-12, Super-1, GH-8, GH-4, Cymit, GHP-5, GHP-11 and Samurai-2. The high resistance genotypes consisted of P/F-5-193-C, GH-14, P/F-10-90A, GH-14, GH-1, Pahat, GH-13, Kawali, GH-33, GH-11 and Samurai-1.

Effect of genotypes on the percentage of damage seeds (PDS): The effect of genotype factor to percentage of damage seeds (PDS) was highly significance ($p<0.01$), both in low or high temperature storage rooms (Table 1). The relationships between genotypes and PDS were presented in Fig. 3. Using value of median with confidence interval 95%, seed resistance to weevil of the 34 genotypes could be grouped into (a) Low resistance genotypes, (b) Moderate resistance genotypes and (c) High resistance genotypes (Table 3). The low resistance genotypes consisted of GH-6, Super-2, UPCA, GH-9, Mandau, GH-8, GH-7, P/W-WHP, GH-5, GH-2 and GHP-29. The moderate resistance genotypes consisted of GHP-5, P/F-5-193-C, GH-12, GH-3, GH-4, Numbu, Samurai-2, GH-33, GH-1 and P/F-10-90A. The high resistance genotypes consisted of Pahat, GHP-1, Super-1, Cymit, GHP-3, GHP-11, Samurai-1, Kawali, Talagabodas, GH-14 and GH-11.

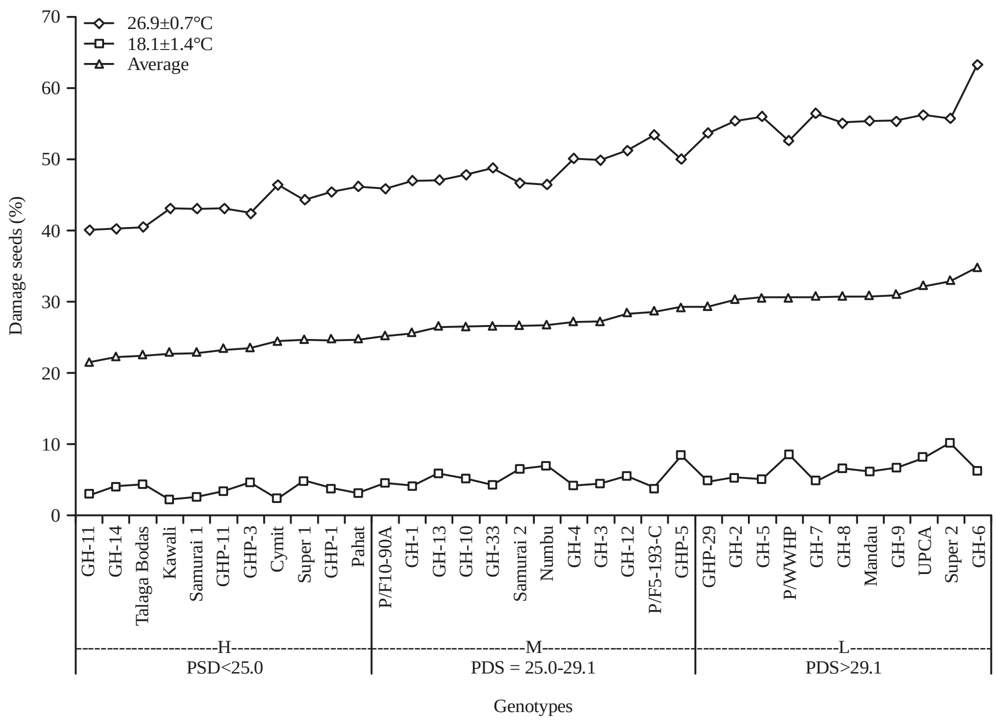

Fig. 3: Relationship between genotypes and percentage of damage seeds (PDS) in low temperature storage, in high temperature storage and in average. The 34 genotypes could be grouped into high resistance (H), moderate resistance (M) and low resistance (L) to weevil

Effect of genotypes to percentage of intact seeds (PIS): The effect of genotype factor to percentage of intact seeds (PIS) was highly significance ($p<0.01$), both in low or high temperature storage rooms (Table 1). The relationship between genotypes and PIS was presented in Fig. 4. Using the value of median with 95% confidence interval, seed resistance to weevil of the 34 genotypes could be grouped into (a) Low resistance genotypes, (b) Moderate resistance genotypes and (c) High resistance genotypes (Table 3). The low resistance genotypes consisted of GH-6, Super-2, GH-7, GH-9, GH-8, GH-5, P/W-WHP, UPCA, Mandau, GH-2 and GHP-5. The moderate resistance genotypes consisted of GHP-29, GH-4, GH-12, P/F-5-193C, Samurai-2, Numbu, GH-3, P/F-10-90A, GH-1, GH-33, GH-10 and Super-1. The high resistance genotypes consisted of GH-13, Pahat, GH-14, Cymit and with GHP-11 Kawali, GHP-1, Samurai-1, GHP-3, GH-11 and Talaga Bodas.

DISCUSSION

The results of this experiment showed that there were different quantity of weevil numbers, percentage of damage seeds and percentage of intact seeds among three testing methods (Table 2). Those differences showed that there was weevil numbers in the testing method-1 as the method with no weevils infested in the testing system. It meant that there might be weevil eggs in the clean seeds of sorghum and the eggs hatch during seed stored. In the method-1, weevil numbers was least compare to those in method-2 and method-3. It was because the method-1 was a control, no weevil infested into the testing system at the beginning of storage. In the method-3, weevil numbers was more than those in the method-2, mainly in the high-temperature storage of 26.9±0.7°C. It could be explained that once weevils got seed they most prefer in the cup, they would stay in that seed cup and no more moving to others genotype seeds cause of no bridge. Table 2 also revealed that there were a positive correlation between weevil numbers and percentage of damage seeds ($r = 0.98$, $p<0.01$) and a negative correlation between weevil numbers and percentage of intact seeds ($r = 0.57$: $p<0.01$), as presented in Fig. 5. It meant that the more weevils numbers existing with seeds, the higher percentage of damage seeds, the lower percentage of intact seeds, the more seeds preferred by the weevil and the lower seed resistance to the weevil. It was in line with Kamara *et al.*[20] report, that there was a high correlation ($r = 0.93$) between grain damage and weevil numbers. It also meant that weevil numbers, percentage of damage seeds and percentage of intact seeds were good indicator variables that could be used for assessing the seed resistance of sorghum genotypes on weevil.

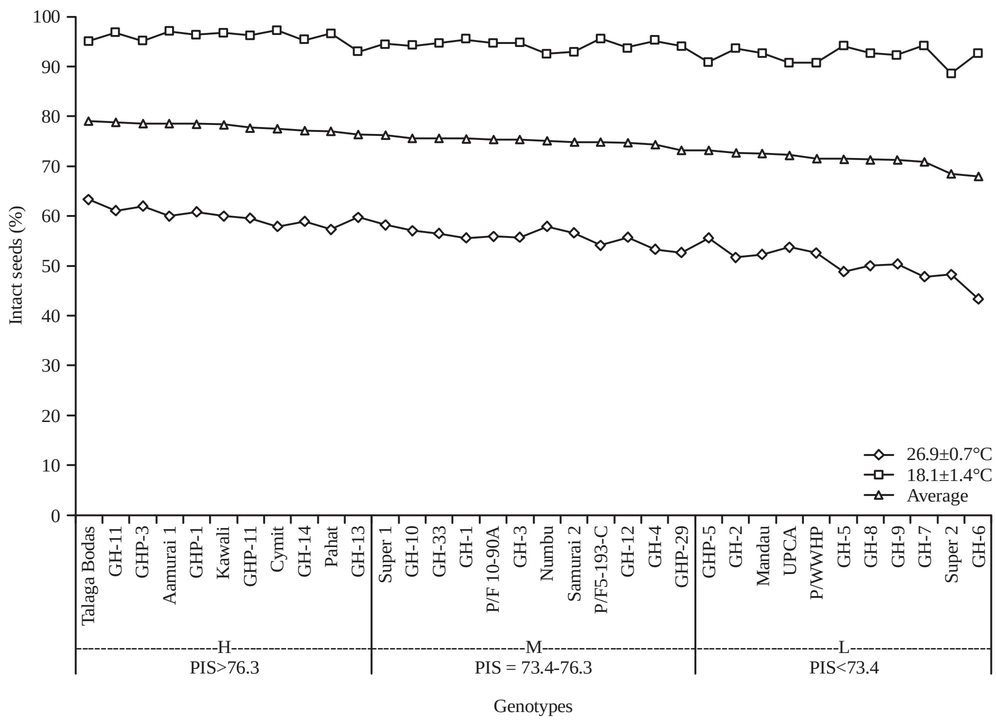

Fig. 4: Relationship between genotypes and percentage of intact seeds (PIS), in low temperature storage, in high temperature storage and in average. The 34 genotypes could be grouped into high resistance (H), moderate resistance (M) and low resistance (L) to weevil

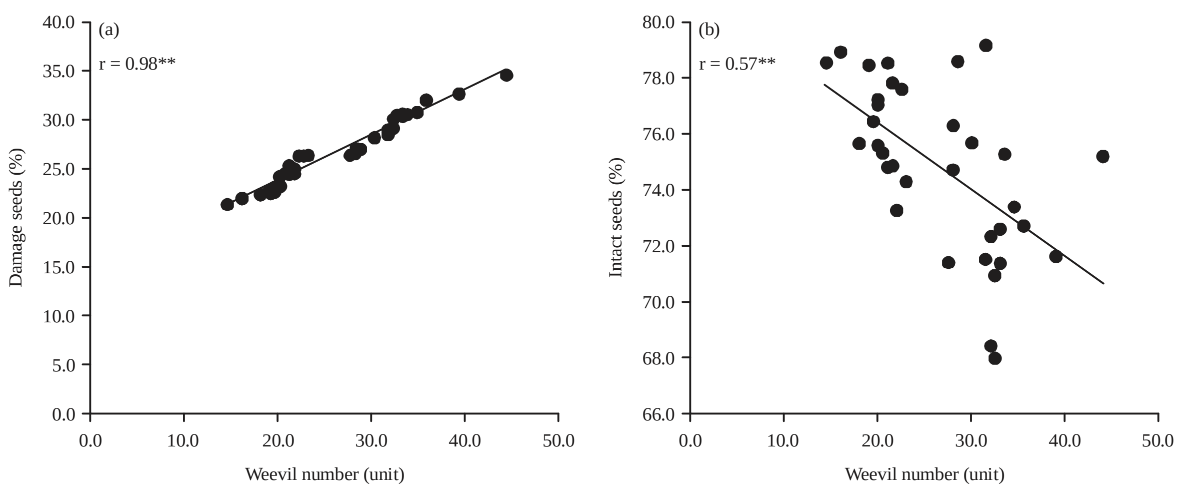

Fig. 5(a-b): Relationship between weevil numbers (*Sitophilus* sp.) with (a) Percentage of damage seeds (r = 0.98, p<0.01) and (b) Percentage of intact seeds (r = 0.57, p<0.01) of 34 genotypes of sorghum [*Sorghum bicolor* (L.) Moench.], degrees of freedom for r value was n-2 = 32. **Highly significant (p<0.01)

The results of assessment of seed resistance to weevil based on WN, PDS and PIS variables (Fig. 2-4) separately were different. For example, using variable of weevil numbers, Numbu was included in the group of low resistance genotypes (L) but using variables of PDS and PIS it was included in the group of medium resistance genotypes (M). The same thing also occurred on P/F-5-193-C, P/F-10-90A and Talaga Bodas. To establish the results of the assessment of the seed resistance of the 34 genotypes of sorghum on the weevil, the three variables were used simultaneously in this experiment as presented in Table 3.

Table 3: Classification of seed resistance (CSR) to weevil (*Sitophilus* sp.) based on each variable separately (CSRs) and based on combine of the three variables (CSRc) into low (L), moderate (M) and high (H) seed resistance

	PDS		PIS		WN		Combine
	%	CSRs	%	CSRs	Unit	CSRs	CSRc
Numbu	34.7	L	75.2	M	44.0	L	L
P/W WHP	32.8	L	71.7	L	39.0	L	L
GH-2	32.1	L	72.7	L	35.5	L	L
GHP-29	30.9	L	73.4	M	34.5	L	L
GH-3	30.7	L	75.3	M	33.5	L	L
Mandau	30.4	L	72.6	L	33.0	L	L
GH-9	30.7	L	71.4	L	33.0	L	L
GH-6	30.6	L	68.0	L	32.5	L	L
GH-7	30.4	L	71.0	L	32.5	L	L
Super 2	30.2	L	68.4	L	32.0	L	L
UPCA	29.2	L	72.4	L	32.0	L	L
Talaga Bodas	28.5	M	79.2	H	31.5	M	M
GH-5	29.1	M	71.5	L	31.5	M	M
GH-10	28.3	M	75.7	M	30.0	M	M
GHP-3	27.1	M	78.6	H	28.5	M	M
Super 1	27.1	M	76.3	M	28.0	M	M
GH-12	26.6	M	74.7	M	28.0	M	M
GH-8	26.5	M	71.4	L	27.5	M	M
GH-4	26.4	M	74.3	M	23.0	M	M
Cymmit	26.4	M	77.6	H	22.5	M	M
GHP-5	26.3	M	73.3	L	22.0	M	M
GHP-11	25.1	M	77.8	H	21.5	M	M
GHP-1	25.4	M	78.5	H	21.0	M	M
Samurai 2	24.6	H	74.9	M	21.5	H	H
P/F 5-193-C	24.5	H	74.8	M	21.0	H	H
P/F 10-90A	24.5	H	75.3	M	20.5	H	H
Pahat	24.3	H	77.0	H	20.0	H	H
GH-1	23.2	H	75.6	M	20.0	H	H
GH-14	23.4	H	77.2	H	20.0	H	H
GH-13	22.7	H	76.5	H	19.5	H	H
Kawali	22.6	H	78.5	H	19.0	H	H
GH-33	22.4	H	75.7	M	18.0	H	H
GH-11	22.1	H	78.9	H	16.0	H	H
Samurai 1	21.5	H	78.6	H	14.5	H	H

PDS: Percentage of damage seeds, PIS: Percentage of intact seeds, WN: Weevil numbers

Table 3 showed that assessing the seed resistance using PDS and WN gave similar results. A slightly different result was given by the assessment using the PIS variable. Thus, the result of the assessment using a combination of three variables would give a better result than using individual variables. In fact, the result of the assessment in combination was the same as the result of the assessment with the PDS or WN separately and slightly different from the result of the assessment using the PIS variable. Therefore, classification of seed resistance of the 34 genotypes of sorghum could be done by using variables of percentage of damage seeds (PDS) or weevil numbers (WN) or combination of WN, PDS and PIS. This makes sense, because the correlation coefficient between WN and PDS was very high (r = 0.98, p<0.01), whereas the correlation coefficient between WN and PIS was quite low (r = 0.57, p<0.01) (Fig. 5).

Generally, in the high temperature storage, the WN was more, the PDS was higher and the PIS was lower than those in low-temperature storage room (Table 2, Fig. 2-4). Here, it appeared that the resistance of sorghum seeds in weevils increased when stored at lower storage temperature than in higher storage temperature. What really happens was that weevil's development and activity decreased in low temperature storage, so that its attacks in the seeds decreased as stated by Koehler[11] that their development was faster in warmer areas than in the cooler one.

Classification of seed resistance, by using combination of the three variables (CSRc), to weevil of the 34 genotypes of sorghum into high, moderate and low resistance groups was based on Table 3. The group of genotypes having low seeds resistance (L) to weevil included 11 genotypes, namely Numbu, P/W-WHP, GH-2, GHP-29, GH-3, Mandau, GH-9, GH-6,

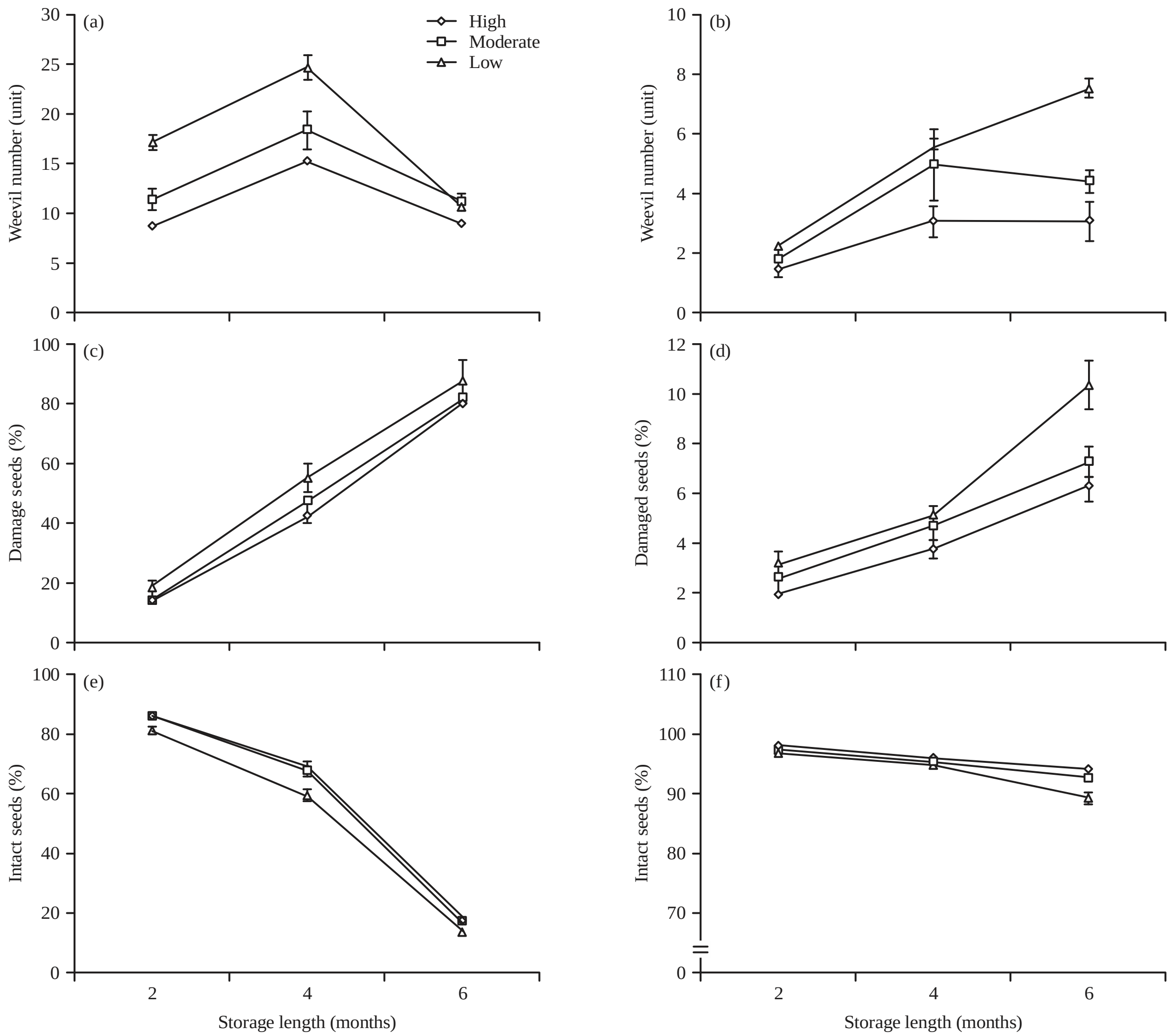

Fig. 6(a-f): (a-b) Development of the weevil numbers (*Sitophilus* sp.), (c-d) Percentage of damaged seeds and (e-f) Percentage of intact seeds during storage at high temperatures of 26.9±0.7°C (left = A, C, E) and at low temperatures of 18.1±1.4°C (right = B, D, F) of the genotypes group of high, moderate and low resistance sorghum seed on weevil

GH-7, Super-2 and UPCA. The group of genotypes having moderate resistance (M) to weevil included 12 genotypes, namely Talaga Bodas, GH-5, GH-10, GHP-3, Super-1, GH-12, GH-8, GH-4, CYMIT, GHP-5, GHP-11 and GHP-1. The group of genotypes having high resistance (H) to weevil included 11 genotypes, namely Samurai-2, P/F-5-193-C, P/F-10-90A, Pahat, GH-1, GH-14, GH-13, Kawali, GH-33, GH-11 and Samurai-1.

According to the data in Table 3, the lowest resistance genotype to weevil was Numbu, with an average weevil numbers of 44 Us., 3.03 times fold than the highest resistance of Samurai-1 with the total weevil numbers of 14.5 Us. or with an average percentage of damage seeds of 34.7%, 1.61 times fold than the highest resistance of Samurai -1 with the average percentage of damage seeds of 21.5%. Similar to Abebe *et al*.[6], who studied the resistance of sorghum seed on weevil was varied among genotypes and shown by the weevil numbers. According to Gotisfu and Belete[12], Abebe *et al*.[6] and Borikar and Tayde[8], the percentage of damaged seeds was also an indicator of the resistance of sorghum seeds on weevil and the results of this study showed that the weevil numbers were in line with the percentage of damaged seeds (Table 2, Fig. 3).

The weevil numbers, percentage of damaged seeds and percentage of intact seeds during storage were presented in Fig. 6. It indicated that the presence of weevil population was dynamics and it seemed there was relation to the number of seeds available as food sources. It meant that the fewer weevil numbers existing with seeds in the more resistance genotype.

The weevil numbers existing with seeds in high temperature storage were more than those in low-temperature storage (Table 2, Fig. 6). The weevil numbers increased from 2-4 months, both in high or low-temperature storages, of the high, moderate or low resistance groups. Then from 4-6 months, at the high-temperature storage, the weevil numbers decreased for all groups. While in the low-temperature storage room, the number of weevils existing with seeds of low resistance genotypes still increased up to 6 months, but in medium and high resistance genotypes, it began decline. It appeared that in high-temperature storage room, the weevil population had been already high after 4 months storage (13-25 units), much higher than those in the low-temperature store (2-6 units). Therefore, at high temperature storage, it was estimated that there was weevil mortality due to interspecific competition and also there were many weevils went out from seed containers as Adetunji[7] pointed out. Weevil mortality due to interspecific competition was higher in low resistance genotypes of sorghum than that in high resistance to weevil[7]. The development of the weevil on sorghum seeds during storage in the low-temperature room was slower than those in the high temperature storage room, which was due to the low temperatures as stated by Koehler[10]. The results showed that on the seed of preference genotypes, the weevil numbers existing with seeds were more than those in non-preference genotypes, both in low or high-temperature storages.

CONCLUSION

There was difference in seed resistance to weevil (*Sitophilus* sp.) among 34 genotypes of sorghum, namely (a) High resistance, (b) Moderate resistance and (c) Low seed resistance genotypes. Decreasing storage temperature from 26.9-18.1°C could increase the seed resistance to weevil (*Sitophilus* sp.) or reduce the weevil number from 14.0 individuals to 3.7 individuals per 200 seeds.

SIGNIFICANCE STATEMENT

This study could differentiate various genotypes of sorghum present in Indonesia based on its seed resistance to weevil during storage. The no-choice method could not clearly distinguish non-preference from preference of weevil to the seeds, so that the separation of sorghum seed resistance based on no-choice method was inadequate. This study used a choice method that allowed the weevil to freely choose their preferred seeds. Thus, the base of seed resistance assessment to weevils in present study is more comprehensive than the earlier literatures. The results of current study will be useful for plant breeders in assembling new sorghum genotypes resistant to weevil, as well as for seed producers in supplying qualified sorghum seeds.

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