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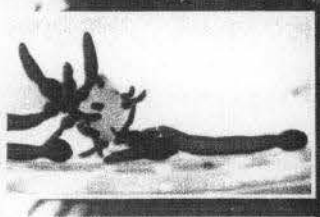

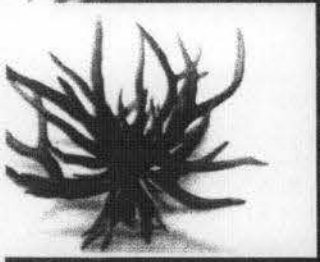

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Caption photo:
Kappaphycus alvarezii (Doty)
Inset (from top to bottom): micropropagule, thallus regeneration and plantlet of *K. alvarezii*

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ENDIANDRA KASSAMENSIS (LAURACEAE), A NEW SPECIES FROM NEW GUINEA

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ABSTRACT

A new species of *Endiandra* (*Lauraceae*) is described from New Guinea. *Endiandra kassamensis* is described based on specimens collected over four decades ago. Unlike most *Endiandra* which grow in lowland forest, *E. kassamensis* is found in high altitude forest. The species is characterized by the presence of staminodia with the absence of staminal glands..

Key words: *Endiandra*, *Lauraceae*, staminal glands, staminodia, endemic, New Guinea

INTRODUCTION

Endiandra is a medium-sized genus within the avocado family (*Lauraceae*) and consists of over 100 tree species. *Endiandra* is generally known for its tree habit characterized by simple, spirally arranged and pinnately-veined leaves. According to van der Werff and Richter (1996), *Endiandra* is grouped together with *Beilschmiedia*, *Cryptocarya* and *Potameia* in the tribe *Cryptocaryeae* based on the type of their inflorescences which is paniculate type II in which the flowers of the ultimate cyme are not strictly oppposite. The flowers are bisexual with 3 stamens (rarely 2 or 6) having 2-celled anthers; the ovary is superior, producing fruits in the form of drupe which are free on the receptacles.

Endiandra glauca is the type species of the genus and was described from Australia (Brown 1810). Australia houses 38 species of *Endiandra* (Hyland 1989) and rest of the species are distributed mostly in Malesian regions with very few in East Asia and Pacific Islands and extending north to southern China. New Guinea is the largest island in Malesian regions and a recent study on the species of *Endiandra* revealed that

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there are 46 species in that island with a high number of endemic species (Arifiani 2012, unpubl.). The species of *Endiandra* occurred generally in lowland forests (from 0 - 600 m above sea level) and the number of species decreases at higher altitude in montane forest (above 1000 m).

Delimiting species of *Endiandra* requires both vegetative and floral characters evaluation. The characters evaluated include indument in all part surfaces, leaf, inflorescence, tepal, stamen, staminal glands, staminodia and fruit. Detailed observation of the characters in several specimens suggested that the specimens of Coode and Dockrill 32655 and Womersley and Vandenberg 37195 represent an undescribed species.

MATERIALS AND METHODS

The description of *Endiandra kassamensis* was done using herbarium specimens available at Herbarium Bogoriense (BO) and loan specimens from Singapore Botanic Gardens (SING). The study was carried out following methods of Rifai (2011) in species enumeration. Specimen characterization was done to collect morphological data by observing the characters of all specimens under the microscope (Table 1). All measurements, the number and states of the characters were noted including their position, color, fragrance, texture, density and shapes. All measurements are for dried specimens or as otherwise stated. Characterization method and botanical terms used

Table 1. Characters observed in the taxonomic study (Kostermans 1957, Rohwer 1993)

Plant parts	Characters
Habit	height; width
Twig	color; indument type, orientation and density
Terminal bud	indument; shape; size
Leaf	arrangement; texture
Leaf blade	shape; size; apex; base; surface
Midrib	texture
Lateral veins	number; angle
Minor venation	reticulation density
Petiole	shape; indument; length
Inflorescence	type; position; length; indument
Pedicel	indument; length
Bract	shape; size
Receptacle	depth; indument
Tepal	opening; shape; size; indument
Stamens	number; shape; indument; size
Glands	number; shape; indument; size
Staminodes	number; shape; indument; size
Pistil	shape; indument; length
Fruit	shape; size

followed Veldkamp (1987). Characters observed were compared and correlated to each other in order to assign specimens to a discrete taxon. Finally, description for each species was created, including information on distribution, habitat and ecology, and notes on the specific characters important for the taxon.

RESULTS AND DISCUSSIONS

Species Description

Endiandra kassamensis Arifiani, *spec. nov.* - Figure 1.

Similar to *Endiandra fulva* vegetatively but *E. kassamensis* has more lateral veins and coarser reticulation. The flowers of *Endiandra kassamensis* bear no staminal glands but staminodes are present. - Type: *Womersley & Vandenberg 37195* (holo BO; iso SING), Kassam Pass, Kainantu, Eastern Highlands District, PNG.

Tree up to 43 m high, 90 cm in diameter. *Twigs* solid, dark brown, glabrous. *Terminal buds* conical, big, with densely pubescent with short appressed hairs. *Leaves* alternate; petiole thin, canaliculate above, ca. 1 cm long, glabrous; blade coriaceous, narrowly elliptic to elliptic, 11-14 x 3-6 cm, glabrous on both surfaces, apex acuminate, base cuneate; midrib flat to slightly impressed above, raised below, both surfaces glabrous; lateral veins diverging, 10-11 pairs, slightly raised, glabrous on both surfaces; minor venation coarsely reticulate, prominent. *Inflorescences* paniculate, bear many flowers, up to 12 cm long, terminal or axillary, with sparse short hairs; bracts caducous; pedicels slender, ca. 3 mm long, with dense curly hairs. *Flowers* brown (fresh), erect, 2 mm in diameter; tepals thin, soft, subequal (inner ones smaller), narrowly ovate, outer ones 1.2-1.5 x 1-1.2 mm, inner ones 1-1.2 x 0.8, with sparse long curly hairs outside, same inside especially basal part at anthers attachment; glands none; stamens 3; anthers somewhat triangular, 1 x 0.6 mm, glabrous; filament short, 0.1 mm long; locules small, roundish; staminodia 3, pentagonal, 0.4 x 0.3 mm, with curly hairs; receptacles deep, with curly hairs; ovary ovoid, 0.6-0.9 mm long, glabrous; style ca. 0.3 mm long; stigma inconspicuous. *Fruits* unknown.

Distribution - Eastern Highlands District (PNG, Figure 2).

Habitat & Ecology - Rain forest, on hillside, subcanopy; alt. 1280-1372 m.

Specimens examined (3 sheets) - Coode & Dockrill 32655 (BO); Womersley & Vandenberg 37195 (BO, SING).

Notes - *Endiandra kassamensis* Arifiani is different from other species of *Endiandra* in New Guinea because of the composition of its flowers. The species bears no glands but interestingly staminodia are present. Vegetatively, *E. kassamensis* is similar to *E. fulva* Teschner but bears more lateral veins and coarser reticulation. *Endiandra kassamensis* is endemic in New Guinea and has a restricted distribution, i.e. in the eastern part of New Guinea (Papua New Guinea) and was not found further West in West Papua. Furthermore, the species grows only in a relatively high altitude forest. According to Rohwer (1993), the diversity of Lauraceae species are higher in lowland forests, which is in agreement with the diversity of *Endiandra* in general except for several species of *Endiandra* including *E. kassamensis* that was only found in higher altitude forests, in the restricted area of Kassam Pass, Kainantu subdistrict.

This fact leads *E. kassamensis* to be considered a rare species. Detailed studies of endemic and rare species of *Endiandra* are important for providing information for decision makers in allocating conservation efforts.

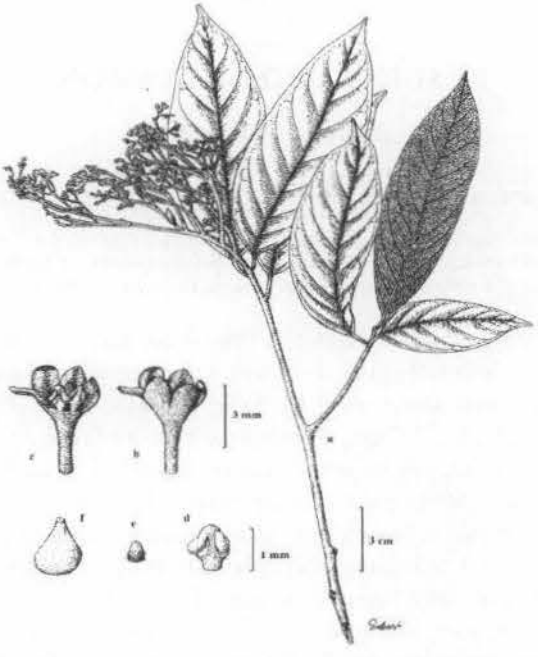

Figure 1. *Endiandra kassamensis* Arifiani. a. habit; b. intact flower; c. flower with 2 tepals removed; d. anther; e. staminode; f. pistil (*Womersley & Vandenberg NGF 37195*).

Figure 2. Species distribution of *Endiandra kassamensis* (▲).

CONCLUSIONS

Endiandra kassamensis is described for the first time in this study. It is a rare species and endemic to New Guinea.

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The first author graciously thanks Prof. Mien A. Rifai for valuable guidance and constructive suggestion during the research and to Dr. Sri S. Tjitrosoedirdjo for valuable discussion and support during the research and preparation of the manuscript. We acknowledge the generosity of the curator of SING herbarium for the loan materials. We would like to thank the anonymous reviewer for the important comments and to Mr. Subari for the botanical line drawings.

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TROPICAL FOREST TYPES IN WEST PAPUA, THE PRESENCE OF FOREST WALLABY (*Dorcopsis muelleri*) AND HUMAN DISTURBANCE

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ABSTRACT

The vegetation in the Nuni Watershed area, part of a tropical lowland forest area in the northern part of Manokwari, West Papua, was classified with Twinspan. The area is important as a natural habitat of the forest wallaby. Four habitat types comprising 6 plant communities could be distinguished belonging to grassland, four different types of open forest and undisturbed primary closed forest. A vegetation table is presented and species composition is described. In each vegetation plot the presence of trails, wallaby droppings, food remains and signs of human disturbance, i.e. logging, hunting and gardening activity, and distance to settlement areas was noted. The presence of Wallabies could only be noted in grassland, open forest with only little logging activity, and in undisturbed closed forest. It is strongly correlated to distance from villages and negatively correlated to logging and hunting. The relation with food plant availability appears to be only low. The results indicate that vegetation structure, vegetation composition and food plant availability are less important than human disturbance. Regulations reducing the disturbance by logging and hunting are urgently needed.

Key words: Wallaby, plant communities, vegetation analysis, wildlife, tropical forest, Papua

INTRODUCTION

The island of New Guinea (Papua New Guinea and West Papua) occupies a phytogeographically important position between Asia and West Melanesia on one hand, and Australia and the Pacific on the other.

In West Papua, many ecosystems occur in a range from the coastal to the alpine zone of which the tropical forest is the dominant ecosystem. Mammalian species are numerous in the tropical forest ecosystems of West Papua. New Guinea hosts a unique fauna of mammals due to its geological history (Petocz 1989; Muller 2005),

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POSTHARVEST QUALITY IMPROVEMENT OF SORGHUM (*Sorghum bicolor* (L.) Moench) GRAINS

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ABSTRACT

The objectives of this study were (a) to investigate the effect of postharvest handling (threshing and storing) methods on the quality of sorghum (*Sorghum bicolor* (L) Moench) grains variety Numbu, in terms of the percentages of damaged grains and seed germination, population growth of *Sitophilus zeamais*, *Fusarium proliferatum* and *F. verticillioides*; fumonisin B_1 and carbohydrate contents, and the percentage of weight loss during storage. The change of moisture contents of sorghum grains was also recorded. Threshing was conducted using wooden stick and a paddy thresher. Sorghum grains were packed in hermetic plastic bags. The conditions inside of the bags were airtight and normal. Each bag with different conditions inside was infested with 10 pairs of *S. zeamais* (1-14 days old). Sorghum was stored for one, two and three months under warehouse conditions. The results showed, that the moisture contents of sorghum were lower than its standard safe moisture content (<14%) during storage. At the beginning of storage, the percentage of damaged grains caused by threshing using wooden stick was higher than that of using a paddy thresher. The increase of percentage of damaged grains was caused among others by increase of *S. zeamais* population under normal oxygen concentration inside of the bag (about 21%), consequently the percentage of weight loss was also increased. The percentage of seed germination of sorghum threshed using a wooden stick was lower than threshed using a paddy thresher. The percentage of seed germination decreased with the increase of storage duration. Population of *F. proliferatum* and *F. verticillioides* decreased with the increase of storage duration. Fumonisin B_1 content of sorghum threshed using a wooden stick was higher than using a paddy thresher during one, two and three months of storage. Fumonisin B_1 contents were considered low. In general, carbohydrate content of sorghum threshed using either wooden stick or a paddy thresher from the beginning up to three months of storage were not significantly different. Threshing using a paddy thresher was better in comparison to threshing using a wooden stick.

Key words: postharvest quality, sorghum, *Sorghum bicolor*

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INTRODUCTION

As foodstuff, sorghum (*Sorghum bicolor* (L) Moench) is the fifth most important cereal after rice, wheat, maize, and barley in the world. Sorghum can adapt to broad agroecology, gives high production, and is more resistant to drought, pests and diseases, compared to other food crop. It has also high nutritional content which is consequently good to be used either as alternative food or feedstuff.

According to Suarni (2001) sorghum has carbohydrate content of 80.42% as compared to 86.45% in milled rice and 79.95% in maize. In terms of protein, sorghum has slightly higher content (10.11%) than milled rice (9.28%), but slightly lower than maize (11.02%). Sorghum's lipid content value (3.65%) is between milled rice (1.88%) and maize (5.42%). The use of sorghum as foodstuff in the form of flour is more beneficial, because it is easier to be processed into food products such as cake, cookies, bread and noodle. The capability of sorghum flour substitution upon wheat flour varied, i.e. for cookies, cake, bread and noodle was 50-75%, 30-50%, 20-25% and 15-20%, respectively (Suarni 2004). Sorghum grains could substitute maize for feed stuff, because the nutritional content of sorghum is not so different from that of maize (Sirappa 2003).

Since long time ago sorghum plant has been recognized by farmers in Indonesia, especially in Java, West Nusa Tenggara and East Nusa Tenggara. Nevertheless, the production of sorghum is still low. Although in Indonesia the production of sorghum is still low compared to other countries such as India, China and United States, it is equally important to pay attention to the postharvest handling of this commodity to maintain its good quality during storage.

Cultivation and development of sorghum are important to anticipate food crisis caused by global warming. In Indonesia, the low production of sorghum grain is due to (a) the nonavailability of appropriate technology for sorghum handling and processing after harvest, (b) the limited knowledge on how to process sorghum grain into various food products, (c) the lower price of sorghum grains compared to milled rice, maize and peanuts.

The postharvest handling (drying, threshing and storing) can affect the quality of sorghum. Dharmaputra *et al.* (2010) reported that based on the surveys conducted in Demak and Wonogiri Regencies in 2010, the postharvest handling of sorghum practiced by farmers and collectors was not carried out appropriately, therefore sorghum grains were easily attacked by insects. The dominant insect species found were *Sitophilus zeamais* and *Tribolium castaneum*. The most common fungi found in sorghum were *Aspergillus flavus*, *Fusarium semitectum* and *F. verticillioides*.

During storage, sorghum could be infested by insects, microorganisms, mites and rats. Insects are considered the most significant cause of postharvest losses. Among microorganisms, fungi are the most important cause of deterioration of stored grains. The role of insects in fungal infection cannot be disregarded. Aside from injuring grains, insects also serve as carriers of fungi. Furthermore, the metabolic activities of insects produce heat and moisture (especially during longterm storage) which stimulate fungal growth. Fungal infection in grains can cause discoloration, decrease

in germination, physical quality and nutritional contents, and also mycotoxin contamination (Sauer *et al.* 1992).

Fumonisins are important mycotoxins, produced mainly by *F. proliferatum* and *F. verticillioides* in several agricultural products worldwide, especially in maize and sorghum (Marasas *et al.* 1988; Abdel-Hafez *et al.* 1990; da Silva *et al.* 2000). The former name of *F. verticillioides* is *F. moniliforme*. According to Desjardins (2006) there are four kinds of fumonisins occurring at significant levels in naturally contaminated grain, i.e. fumonisin B_1, B_2, B_3 and B_4. The most toxic among these four kinds of fumonisins is fumonisin B_1 which can cause leukoencephalomalacia in equines (Marasas *et al.* 1988) and rabbits, pulmonary edema in swine (Bucci *et al.* 1996; Harrison *et al.* 1990) and it has been reported as a probable cause of esophageal cancer in humans (Marasas 2001). A high incidence of esophageal cancer has been observed in certain geographic areas and ethnic groups in Africa, Asia and Latin America.

In Indonesia, no research has been done on fumonisin level in sorghum. The method of postharvest handling is one of the factors that can affect the quality of sorghum. However, the postharvest practices in Indonesia are still inadequate, it is important to conduct research on the effects of different postharvest treatments on the quality of sorghum grain. This study is a continuation of the research conducted last year.

The objectives of the research were: (1) to investigate the effects of postharvest handling (threshing and storage) on the quality of sorghum grains, in terms of the percentages of damaged grains and seed germination, population growth of *S. zeamais*, *F. proliferatum* and *F. verticillioides*, fumonisin B_1 and carbohydrate contents, and the percentage of weight loss; (2) to record the change of moisture contents of sorghum grains during storage, and (3) to recommend proper postharvest handling methods to ensure the quality of sorghum grains during storage.

The research results should provide recommendations to farmers, collectors, food and feed industries on the most adequate postharvest handling practices (threshing and storage) for sorghum to maintain good quality of grain during storage.

MATERIALS AND METHODS

Variety of Sorghum

The variety of sorghum used in this study was Numbu, cultivated by PT Tri Fondasi Indonesia in Balaraja Subdistrict, Tangerang Regency, West Java. The Numbu grains were harvested 95 days after sowing.

Methods of Harvesting, Drying, Threshing and Winnowing

Sorghum was harvested by cutting the panicle from the standing stalk using a sickle. Sorghum in the form of panicles was sun-dried on tarpaulin. Drying was conducted up to moisture content of about 13%. Threshing was done using a wooden stick and a paddy thresher. After threshing, grains were separated from dirt and chaff by winnowing. Sun-drying, threshing and winnowing were conducted in the location

where sorghum was cultivated. Sorghum grains were then transported to SEAMEO BIOTROP, Bogor, by a car equipped with air conditioning.

Methods of Packaging and Storing

Prior to packaging, sorghum grains were:

(a) fumigated with phosphine for five days at 2 grams/ton of sorghum to control insect pest that may exist,
(b) checked for the percentage of damaged grains. Damaged grains included cracked and broken grains caused by threshing.

The grains were packed using hermetic bags under airtight conditions, i.e. oxygen concentration inside was about 18%, and under normal conditions (oxygen concentration inside was about 21%).

Each bag type of packaging material contained 2 kg of sorghum grains. Characteristics of plastic packaging material used to pack sorghum grains are presented in Table 1. In three replicates, inside of each bag type with different oxygen concentrations were treated as follows:

(a) infestation with ten pairs of adult (1-14 days old) *Sitophilus zeamais*,
(b) different method of threshing, and
(c) different storage duration.

The bags designated as "control" were not infested with *S. zeamais*, but were also subjected to different methods of threshing as well as storage durations. Sorghum grains were stored for one, two and three months under warehouse conditions. Bags containing sorghum were placed on wooden shelves randomly. The temperature and relative humidity of the storage were recorded using a thermohygrograph.

Table 1. Laboratory analyses of plastic packaging material*

Parameter test	Condition of sample	Unit	Test method	Test result	Uncertainty at 95% confidence level, k=2
WVTR (Water Vapour Transmission Rate) Temperature = 37.8 °C RH = 100% Thickness of sample = 82.5 µm	Good	g/m²/ day	ASTMF 1249-20062	2.8946	± 0.3619

*Analysed by Laboratory of Test and Calibration, The Agency for Chemical and Packaging, Jakarta, Indonesia

Sampling Methods

Grain samples were collected from each bag before storage and subsequently every month thereafter until three months of storage. In samples infested with *S. zeamais*, the insects were separated from the sorghum grains using a sieve, they were then preserved in vials containing 70% ethanol. After that, each sample was divided three times using a box sample divider to obtain working samples for the determination of moisture content, percentages of damaged grains and seed germinations, population of *F. proliferatum* and *F. verticillioides*; fumonisin B_1 and carbohydrate contents, and a reserve sample.

Determination of Quality Parameters

The following quality parameters were determined in the experiments:
Moisture content, percentages of damaged grains, seed germinations, populations of *S. zeamais*, *F. proliferatum* and *F. verticillioides*; Fumonisin B_1 and carbohydrate contents, percentage of weight loss.

Moisture content of sorghum (based on wet basis) was determined as soon as samples were collected using DELMHORST Model G-7 Moisture Meter. This instrument has been caliberated and cross-checked using oven method. Two replicates were used for each sample.

Damaged grains were collected after one, two and three months of storage including cracked, broken and damaged grains (damage caused by *S. zeamais* or fungi). The number of grains used for the determination of damaged grain percentage was 300 per sample.

Percentage of seed germination was determined based on blotter method (Mathur and Kongsdal 2001). Population growth of *S. zeamais* was determined based on the number of adult insects per kg of each sample. *Fusarium verticillioides* and *F. proliferatum* were isolated and enumerated using a serial dilution method followed by pour plate method on Dichlorane Chloramphenicol Peptone Agar (DCPA) (Pitt & Hocking 2009). Fumonisin B_1 and carbohydrate contents were determined using Liquid Chromatography-Mass Spectrophotometry (LC-MS) (Zöllner & Mayer-Helm 2006) and SNI (1992) methods, respectively.

The percentage of weight loss was determined at the end of storage. Grain samples contained in each bag were weighed before and at the end of storage. Grain samples were taken periodically from each bag and weighed.

Statistical Analyses

The data were analyzed using Completely Randomized Factorial Design with four factors. The first, second, third and fourth factors were the method of threshing, oxygen concentrations inside of the bags, presence or absence of *S. zeamais*, and storage duration, respectively.

RESULTS AND DISCUSSIONS

Moisture Content

Moisture content of grains is one of the important factors that affected the deterioration of grains during storage. High moisture content will give an opportunity for fungal growth. SNI (1992) defines 14% as the maximum moisture content of sorghum grains during storage.

Method of threshing, duration of storage and their interaction gave very significant differences in moisture content of sorghum grain. Moisture content of sorghum threshed using a wooden stick at the beginning of storage, subsequently after 1, 2 and 3 months of storage was significantly different from samples threshed using a paddy thresher during the same periods.

The lowest moisture content (13.30%) was found in sorghum grain threshed using a wooden stick before storage and after two months of storage (Table 2). The highest moisture content (13.72%) was found in sorghum grain threshed using wooden stick after three months of storage. It was significantly different from that threshed using a wooden stick before storage or after two months of storage.

According to Christensen *et al.* (1992) moisture content is always in equilibrium with the relative humidity of storage room. Bala (1997) reported, that moisture content is also affected by the temperature of storage room. In this study, the range and mean of the temperature of storage room during storage were 26.8 - 29.3°C (28.1°C), while the range and mean of relative humidity of storage room were 47.5 - 70.8% (64.5%) (Table 3).

Lacey and Magan (1991) reported that among the microorganisms which colonize grains, fungi are the most tolerant to low relative humidity, consequently fungi has an important role in the deterioration of grain.

Table 2. Moisture content of sorghum grains threshed using wooden stick and a paddy thresher during storage

Duration of storage (month)	Moisture content (%)	
	Wooden stick	Paddy thresher
	Mean ± STD	Mean ± STD
0	13.30 ± 0.08 a	13.38 ± 0.05 b
1	13.55 ± 0.05 c	13.67 ± 0.15 de
2	13.30 ± 0.09 a	13.52 ± 0.12 c
3	13.72 ± 0.07 e	13.64 ± 0.09 d

Note: Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

Table 3. Range and mean values of temperature and relative humidity during storage

Duration of storage (month)	Range and mean of temperature (°C)	Range and mean of relative humidity (%)
0-1	27.4-29.3 (28.3)	54.0-70.8 (59.8)
1-2	26.8-28.9 (28.3)	47.5-68.6 (57.7)
2-3	27.2-28.2 (27.8)	48.7-58.6 (57.9)

Percentage of Damaged Grains

Method of threshing, duration of storage and their interaction gave very significant differences (at 99% significance level) in the percentage of damaged grain, while the interaction among method of threshing, infested with insects, oxygen concentration and duration of storage affected less significantly (95% significance level) the percentage of damaged grain.

At the beginning of storage, the percentage of damaged grain of sorghum threshed using a wooden stick was higher and significantly different from that threshed with a paddy thresher. The percentage of damaged grain in each treatment combination increased and was significantly different during three months of storage. The sorghum grains threshed either using a wooden stick or a paddy thresher, not infested with insects, packed under low or normal oxygen concentrations did not gave any significant difference on the percentage of damaged grains after three months of storage (Table 4).

The lowest percentage of damaged grain was found in sorghum threshed using a paddy thresher, not introduced with insect and stored under low oxygen concentration (MS0H) at the beginning of storage (5.00%), while the highest was found in sorghum threshed using a wooden stick, infested with insect and stored under normal oxygen concentration (KS1N) after three months of storage (21.47%) (Table 4).

According to Dobie *et al.* (1991) *S. zeamais* is an important insect pest in stored grain. In Indonesia *S. zeamais* could be a dominant insect species in milled rice and maize. The adult can live for several months up to one year. Their eggs, larvae and pupae are found inside of grain. Dharmaputra *et al.* (2010) reported, that the dominant insect species of sorghum stored at farmer and collector levels in Wonogiri and Demak Regencies were *S. zeamais* and *T. castaneum*.

Table 4. Percentage of damaged grains of sorghum caused by various treatments

Treatment	Duration of storage (months)			
	0	1	2	3
KS0H	9.90 ± 0.00 fegd	10.63± 2.63 fcegd	12.08 ± 2.23 cebd	20.20 ± 0.08 a
KS0N	8.44 ± 1.66 fhgi	11.62 ± 0.16 fcebd	14.60 ± 0.00 b	18.48 ± 2.53 a
KS1H	7.66 ± 1.26 hjgi	12.53 ± 2.80 cbd	13.33 ± 1.54 cb	19.73 ± 1.62 a
KS1N	9.38 ± 0.35 fhegd	10.03 ± 3.03 fegd	11.99 ± 2.95 cebd	21.47 ± 0.83 a
MS0H	5.00 ± 0.22 j	8.98 ± 0.22 fhegi	9.76 ± 0.19 fegd	10.45 ± 0.00 fcegd
MS0N	5.04 ± 0.36 j	5.92 ± 0.12 ji	7.79 ± 0.82 hjgi	9.45 ± 0.45 fhegd
MS1H	6.20 ± 0.45 hji	9.01 ± 0.00 fhegi	8.93 ± 2.06 fhegi	10.05 ± 0.05 fegd
MS1N	5.07 ± 0.47 j	7.74 ± 4.46 hjgi	8.91 ± 1.63 fhegi	9.87 ± 0.56 fegd

Note: Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

K = wooden stick; S0 = not infested with *S. zeamais*; N = normal oxygen concentration (±21%)
M = a paddy thresher; S1 = infested with *S. zeamais*; H = low oxygen concentration (± 18%)

The existence of damaged grain before storage was due to the different threshers. During storage, the increase of damaged grain in sorghum infested with insects could be caused by insect and fungal attacks, while that not infested with insects may be due to fungal infection.

Percentage of Seed Germination

Effects of threshing and storage duration was highly different in the percentage of seed germination. Percentage of seed germination in sorghum threshed using a wooden stick (91.04%) was lower and significantly different from that of sorghum threshed using a paddy thresher (93.33%) (Table 5). It was stronger correlated with the percentage of damaged grain in sorghum threshed using a wooden stick than in grain threshed with a paddy thresher. Percentage of seed germination during storage decreased with the increase of storage duration (Table 6). Percentage of seed germination at the beginning of storage (93.88%) was significantly different from that after one (91.96%), two (91.88%) and three months of storage (91.04%). Percentage of seed germination after one, two and three months of storage was not significantly different. According to Neergard (1979) fungal infection in the embryo of seed is a factor causing the decrease of seed germination during storage. Percentage of seed germination after three months of storage was more than 90%, thus the percentage is still higher than the minimum standard germination of seed, i.e. 70% (Directorate General of Food Crops 1984).

The capability of seed to germinate is affected by the atmosphere composition of storage room, but its effect is lower compared to the moisture content and the temperature of the storage (Priestley 1986).

Table 5. Percentage of seed germination in sorghum threshed with a wooden stick vs paddy thresher

Thresher	Seed germination (%)
Wooden stick	91.04 a
A paddy thresher	93.33 b

Note: Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

Table 6. Percentage of seed germination in sorghum grains during storage

Duration of storage (month)	Seed germination (%) Mean ± STD
0	93.88 ± 4.07 a
1	91.96 ± 2.20 b
2	91.88 ± 2.47 b
3	91.04 ± 3.22 b

Note: Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

Population of *F. proliferatum* and *F. verticillioides*

Population of F. proliferatum

The duration of storage gave very significant difference (99% significance level) to the population of *F. proliferatum*, while the interaction between the infestation by insects and the duration of storage, and the interaction among the four factors (method of threshing, presence of *S. zeamais*, oxygen concentration and duration of storage) gave significant difference (95% significance level) to the population of *F. proliferatum*.

Population of *F. proliferatum* in sorghum subjected to different postharvest treatments differed in the samples examined immediately after harvest but no clear trend could be detected. In contrast, no significant difference could be detected between treatments after 1, 2 and 3 months in storage (Table 7). The population of *F. proliferatum* in sorghum subjected to various treatments and storage duration fluctuated considerably resulted to very high standard deviation. The fluctuation was probably due to the existence of other fungal species which were antagonistic or synergistic to the growth of *F. proliferatum*. The population of *F. prolliferatum* in grain subjected to various treatments decreased with the increase of storage duration.

Population of F. verticillioides

The duration of storage gave significant difference in *F. verticillioides* population. Population of *F. verticillioides* decreased significantly with the increase of storage duration (Table 8). The population of *F. verticillioides* at the beginning of storage (1370 cfu/g) was significantly higher than that after three months of storage (433 cfu/g). The decrease of *F. verticillioides* population was probably due to the existence of other fungal species which were antagonistic to the growth of *F. verticillioides*.

According to Neergaard (1979) there are two groups of fungi infecting grains, i.e. field fungi and postharvest fungi. *Fusarium* belongs to field fungi, while *Aspergillus, Eurotium* and *Penicillium* belong to postharvest fungi. During storage, the activity of field fungi often stops, because they need high relative humidity (≥ 90%).

Table 7. Population of *Fusarium proliferatum* (cfu/g) in sorghum grains related to various treatments

Treatment	Duration of storage (month)			
	0	1	2	3
KS0H	7333.33 ± 10540.44 ba	433.33 ± 133.50 c	289.00 ± 329.02 c	311.00 ± 371.55 c
KS0N	1855.67 ± 650.07 c	933.33 ± 851.25 c	133.33 ± 88.44 c	77.67 ± 134.52 c
KS1H	755.67 ± 680.58 c	578.00 ± 943.70 c	1444.67 ± 1924.89 c	333.33 ± 296.52 c
KS1N	2677.67 ± 2117.54 bc	377.67 ± 77.36 c	533.33 ± 695.72 c	300.00 ± 185.71 c
MS0H	1700.00 ± 1010.79 c	411.00 ± 416.61 c	500.00 ± 433.35 c	266.33 ± 57.74 c
MS0N	9155.67 ± 8592.37 a	167.00 ± 0.00 c	113.00 ± 72.11 c	255.33 ± 385.09 c
MS1H	1516.50 ± 118.09 c	1167.00 ± 707.11 c	2033.50 ± 2781.05 c	233.50 ± 47.38 c
MS1N	1333.25 ± 585.33 c	358.50 ± 421.22 c	933.25 ± 968.68 c	1025.00 ± 1540.18 c

Note: Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

Table 8. Population of *Fusarium verticillioides* during storage

Duration of storage (month)	Population of *F. verticillioides* (cfu/g) Mean ± STD
0	1370.88 ± 1320.68 a
1	1293.04 ± 2202.69 ba
2	1157.38 ± 1491.77 ba
3	433.00 ± 590.17 b

Note: Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

Fumonisin B_1 Content

Method of threshing and duration of storage, and their interaction gave very significant differences in fumonisin B_1 content. Fumonisin B_1 content in sorghum threshed using a wooden stick was higher and significantly different from that of sorghum threshed with a paddy thresher after one, two and three months of storage (Table 9). Fumonisin B_1 content in sorghum threshed using a wooden stick fluctuated and showed significant differences at various points in time during storage. The content in sorghum threshed with a paddy thresher also fluctuated, but showed no significant differences between sampling times. The fluctuation of fumonisin B_1 content in sorghum was probably due to the existence of certain strains of *F. verticillioides* which can produce fumonisin B_1.

The lowest fumonisin B_1 (1.58 ppb) was found in sorghum threshed using a wooden stick at the beginning of storage, while the highest in sorghum also threshed using a wooden stick after one month of storage (27.55 ppb).

FAO (2004) reported the maximum allowable fumonisin B_1 content in some countries. In France the maximum fumonisin B_1 content allowed in cereals and their processed products is 1000 ppb, in Cuba for maize and milled rice 1000 ppb, in Switzerland for maize 1000 ppb.

The existence of F. *moniliforme* and other toxigenic species of *Fusarium*, and fumonisin production in the field and their products are determined by environmental factors in the field, during transportation and storage (Gamanya & Sibanda 2001).

Table 9. Fumonisin B_1 content (ppb) in sorghum grains threshed using a wooden stick and a paddy thresher during storage

Duration of storage (month)	Wooden stick Mean ± STD	Paddy thresher Mean ± STD
0	1.58 ± 0.81 a	1.94 ± 1.47 a
1	27.55 ± 12.87 d	3.22 ± 2.71 a
2	20.43 ± 7.56 c	4.65 ± 4.66 a
3	12.57 ± 12.25 b	2.43 ± 3.32 a

Note: Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

Carbohydrate Content

The duration of storage and the interaction between method of threshing were very significant (99% significance level). The carbohydrate content in sorghum before storage (67.33%) was not significantly different from that after two (68.64%) and three months (67.02%) of storage, but it was significantly different from that after one month of storage (70.81%) (Table 10).

The carbohydrate content in sorghum threshed using a wooden stick and a paddy thresher after one and two months of storage was significantly different, while the content at the beginning of storage and after three months of storage was not significantly different. The lowest carbohydrate content was found in sorghum threshed using a paddy thresher at the beginning of storage (65.98%), while the highest content was found in sorghum threshed using a paddy thresher after one month of storage (74.11%).

Suarni (2001) reported that carbohydrate content in sorghum was 80.42%. In this study the range of carbohydrate contents in samples that had been threshed using wooden stick was 66.69 - 71.28% during storage, while the content in sorghum threshed using a paddy thresher was 65.98 - 74.11% during storage (Table 11). The difference of carbohydrate contents in this study and that of Suarni (2001) was probably due to the difference of sorghum variety and the method of cultivation. Garraway and Evans (1984) reported, that carbon source needed for fungal growth were (among others) the carbohydrates (e. g. monosachharides). The capability of fungi to use sugars could be different among fungal species, even sometimes among different strains of the same species.

Table 10. Carbohydrate content in sorghum grains during storage

Duration of storage (month)	Carbohydrate content (%) Mean ± STD
0	67.33 ± 3.33 b
1	70.81 ± 5.57 a
2	68.64 ± 4.05 b
3	67.02 ± 1.45 b

Note: Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

Table 11. Carbohydrate content (%) in sorghum grains threshed using a wooden stick and a paddy thresher during storage

Duration of storage (month)	Wooden stick	Paddy thresher
	Mean ± STD	Mean ± STD
0	68.68 ± 4.18 ab	65.98 ± 1.32 a
1	67.51 ± 3.57 a	74.11 ± 5.34 c
2	71.28 ± 2.28 b	66.00 ± 3.71 a
3	66.69 ± 1.48 a	67.36 ± 1.41 a

Note: Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

Sitophilus zeamais Population

The method of threshing and duration of storage differ very significant by (99% significance level) in the population of adult *S. zeamais*, while the interaction between the two factors gave a significant difference (95% significance level). Population of *S. zeamais* in sorghum threshed using a wooden stick after one and three months of storage was higher and significantly different from that of samples threshed with a paddy thresher (Table 12). In general *S. zeamais* population either in sorghum threshed using a wooden stick or a paddy thresher increased during storage. According to Dobie *et al.* (1991) the actual length of the life cycle of *S. zeamais* depends also upon the type and quality of grains being infested, i.e. in different varieties of maize, mean development periods of *S. zeamais* at 27°C and relative humidity 70% have shown to vary from 31 to 37 days.

Table 12. Population of adult *Sitophilus zeamais* (number/kg) in sorghum grains threshed using wooden stick and a paddy thresher during storage tests

Duration of storage (months)	Wooden stick	Paddy th resher
	Mean ± STD	Mean ± STD
0	10.00 ± 0.00 a	10.00 ± 0.00 a
1	20.38 ± 3.37 c	13.62 ± 1.81 b
2	15.98 ± 3.73 b	15.29 ± 1.97 b
3	21.11 ± 2.40 c	15.02 ± 1.16 b

Note: Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

Percentage of Weight Loss

The duration of storage gave very significant difference (99% significance level) in weight loss of sorghum. The percentage of weight loss increased and differed significantly with the increase of storage duration (Table 13). The weight losses of sorghum at the beginning of storage, subsequently after one, two and three months of storage were 1.62, 1.92, 2.21 and 2.30%, respectively. The increase of weight loss was due among others by the increase of the percentage of damaged grain (Table 4) and population of *S. zeamais* (Table 12) during storage.

Table 13. Percentage of weight loss of sorghum grains during storage

Duration of storage (months)	Weight loss (%) Mean ± STD
0	1.62 ± 0.44 a
1	1.92 ± 0.54 b
2	2.21 ± 0.51 bc
3	2.30 ± 0.49 c

Note: Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

CONCLUSIONS

The moisture content of sorghum grain subjected to various postharvest treatments was lower than that of safe moisture content of sorghum for storage (< 14%). At the beginning of storage the percentage of damaged grains of sorghum threshed using a wooden stick was higher than that of threshed using a paddy thresher. The percentage of damaged grain in each treatment increased with the increase of storage duration. After three months of storage the highest percentage of damaged grain was found in sorghum threshed using a wooden stick, infested with *Sitophilus zeamais*, and stored under normal oxygen concentration (± 21%). The seed germination percentage of sorghum threshed using a wooden stick was lower than that of samples threshed with a paddy thresher. During storage the percentage of seed germination decreased with the increase of storage duration.

Populations of *Fusarium proliferatum* and *F. verticillioides* decreased with the increase of storage duration. Fumonisin B_1 content in sorghum threshed with wooden stick was higher than that of samples threshed with a paddy thresher during one, two and three months of storage. Fumonisin B_1 contents were considered low. In general carbohydrate content in sorghum threshed using either wooden stick or a paddy thresher from the beginning of storage up to three months of storage was not significantly different. After three months of storage, *S. zeamais* population either in sorghum threshed using wooden stick or a paddy thresher was higher and significantly different than at the beginning of storage. The percentage of weight loss of sorghum increased with the increase of storage duration. After three months of storage the percentage of weight loss was higher and and significantly different compared to that at the beginning of storage or any other sampling time before three months. The two different oxygen concentrations inside of the bags did not produce any significant difference in the quality of sorghum. Threshing using a paddy thresher was better in comparison to threshing using a wooden stick.

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