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IMPACT OF PRODUCTION INPUTS AND TIMING ON PADDY YIELD AND CRACKING IN NORTHERN GHANA

BY

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THESIS SUBMITTED TO THE DEPARTMENT OF AGRONOMY, FACULTY OF AGRICULTURE, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CROP SCIENCE

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DECLARATION

I hereby declare that this work is as a result of my own research and that no previous submission of contents of this work has been made for a Degree in this University or another elsewhere. Work by others, which served as source of information has been duly acknowledged by reference to the authors.

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ABSTRACT

Under rain-fed conditions, perfumed rice production in Northern Ghana is associated with high paddy cracking during milling. High breakages due to cracks do not meet the prevailing consumer preference for whole grains and results in low market value for the resource-constrained farmer. In this study, 4 perfumed rice varieties, 3 split application regimes of nitrogen, 6 staggered planting times, 6 staggered harvesting times and staggered storage duration from harvest to 6 months of storage were used to identify the best combination of factors that are associated with low cracking. The field experiment was a 3 x 4 x 6 factorial experiment consisting of three Nitrogen application regimes (1 basal, 1 top-dressing; 1 basal, 2 top-dressing; and 1 basal, 3 top-dressing), four rice varieties (AGRA, Gbewaa, Exbaika and Perfumed Irrigated), and six planting dates. The experiment was laid out in a randomized complete block design with three geographically distinct locations serving as replicates. Growth and yield parameters as well as grain moisture and cracking were determined. The results indicated a mixed factorial interaction for all measured variables. While variety and split N-application regime less affected paddy growth and yield, favorable growth and yield parameters ($P < 0.05$) were observed for early planting and early harvesting. Similarly, early planting, early harvesting and short storage duration reduced paddy cracking compared to late treatments ($P < 0.05$). For all treatment combinations, milling within two weeks after harvesting was associated with lower cracking as long as the harvesting cycle did not exceed the fourth cycle. After the second month of storage, percentage cracking was high, approaching 90% in most cases.

To enable straight milling and reduce cracking, early planting, early harvesting and less than two months of storage is recommended for perfumed rice production.

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DEDICATION

I dedicate this work to my family, my mentors and to the memory of my late grandfather, Very Reverend Daniel Baah - Odoom (1935-2005) – Diocesan Bishop of Methodist Church of Ghana, Agona Swedru -a great lover of children.

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CHAPTER ONE

1.0 Introduction

Rice is a significant household crop that serves as the main ration for majority of the world's population and a quarter of the carbohydrate consumed worldwide (Kubo and Purevdorj, 2004). Globally, it is the second most important cereal accounting for 27% of cereal production (Cottyn *et al*., 2001). The crop provides the basic economic activity for rural households worldwide. Therefore, the production of rice with less broken grains, whilst maintaining the highest possible nutrients has been the main objective of paddy processing companies (Addison *et al*., 2015).

In Ghana, rice comes after maize and contributes 10% of the total cereal production (MOFA, 2010). Ghana has all the favourable production conditions to grow rice throughout the year (Asuming-Brempong and Osei-Asare, 2007). Meanwhile, the country is unable to meet local demand (Vincent, 2012), although the average yield of Ghana's production has increased to about 2200 kg/ha as of 2000 (MOFA, 2010). The yield improvement was as a result of the increase of land area dedicated to rice cultivation (MOFA, 2010).

In an effort to facilitate large scale economic growth and poverty reduction, Ghana promotes the cultivation of best improved domestic aromatic/ perfumed varieties to be produced by farmers. Such aromatic/ perfumed rice varieties include: Jasmine 85/ Gbewaa, Agra rice, Exbaika, Perfumed Irrigated and Aromatic short. Local paddy farmers are battling with problems of market access for local rice and it can be resolved by growing rice varieties that will meet consumer needs and satisfy their preferences

(Adu-Kwarteng *et al*., 2003). In the savannah ecological zone of Ghana, where 30% of Ghana's rice is produced (Wiredu *et al*., 2015), the bulk of paddy producers are beginning to use Jasmine 85/ Gbewaa and Agra rice varieties, which are mostly in high demand when straight milled (Addison *et al*., 2015).

Nitrogen (N) is a vital plant nutrient and the main component of many important organic compounds. It improves the root system, which has great significance in absorption of water and nutrients from the soil (Gregory, 1994; Robinson *et al*., 1994). Deficiency in nitrogen is the main nutritional disorder inhibiting crop outputs globally (Baligar, 2001). Efficient use of nitrogen in crop production is therefore essential in order to maximize crop output while preserving environmental safety (Fageria *et al*., 2014). The nitrogen requirement of paddy can alter from field to field, season to season and year to year because of high variability in soil N supplying capacity and plant development due to changes in weather conditions (Lassaletta *et al*., 2014).

Fertilizer nitrogen use efficiency can be increased through the best timing of application to coincide with the stages of peak requirement of the crop (Kaur *et al*., 2006). The method for maximizing nitrogen fertilizer efficiency is to apply recommended rate of the fertilizer in accordance with the prevailing agronomic practices, as well as to aim at maintaining synchrony between crop requirement and nitrogen supply (Dobermann, 2007).

1.1 Problem statement and justification

Though straight-milled aromatic/ perfumed rice is preferred by the Ghanaian market (Angelucci *et al*., 2013), but the production of straight-milled aromatic rice across northern Ghana is associated with many environmental constraints that make it difficult to achieve. As an example, the biggest rice processing mill in Africa, Avnash Industries Limited, is not able to straight-mill paddy at the required volume as there is between 98-100% cracking of aromatic paddy during milling, rendering the paddy unsuitable for straight-milling (Personal communication with Avnash Industries Limited). As a result, the best way to mill paddy is to parboil before milling. The parboiling process melts and cements the cracks, enabling whole milling and reducing breakages (Ayamdo *et al*., 2013). The parboiling process on the other hand, results in the loss of the aromatic quality (Garibold, 1984), a characteristic which is preferred by most Ghanaian consumers (Danso-Abbeam *et al*., 2014).

Consequently, most of the straight-milled perfumed rice is imported into the country, with an increasingly huge negative consequence on the domestic rice industry and the Ghanaian economy as well (Angelucci *et al*., 2013). The climatic issue is caused by a natural phenomenon called the Harmattan, which is a low humidity, dry weather condition that sets off between November and February of each year (Padi, 2017). Currently, harvesting of the bulk (84%) of rain-fed paddy in the northern region coincides with the Harmattan dry season (November-February). The low humidity during harvest time hastens drying and increases the tendency of the paddy to crack and break when milled (Thompson *et al*., 1992). Harvesting, storing and milling at a time when there is relatively high atmospheric humidity may help address crackness in harvested paddy (Dobermann, 2007). Currently, this is attainable only under irrigated rice cultivation, which constitutes less than 16% of total paddy production (Millennium Development Authority, 2010). For rain-fed paddy production system, this may require identification of a suitable window in the season for planting that will result in harvesting at a time that atmospheric humidity is still relatively high.

In addition to inappropriate time of harvesting (time that coincides with the dry harmattan winds), the length of storage has been postulated to affect the cracking of harvested paddy (Akowuah *et al.,* 2012; Tsado *et al*., 2015). Across northern Ghana, smallholder farmers tend to hold on to their stocks of paddy for as long as they deem necessary to enable them obtain more competitive prices in the open market. Incidentally, this may affect them negatively as the condition of the paddy may deteriorate during storage, example, through loss and gain of moisture that may cause differential stresses in the grain. Ideally, smallholder farmers are encouraged to sell off their paddy as soon as it is harvested. However, for those who may still opt to keep stocks and who may not be able to sell as soon as possible, it is necessary to identify the optimum length of storage that minimizes loss of moisture content and therefore reduces the tendency of the stored paddy to crack and break when straight-milled.

Several environmental and genetic factors have also been identified to influence rice milling performance. Among the primary variables are the daily fluctuations in relative humidity, as well as temperature during rice maturity and variety susceptibility to crackness (Kunze and Hall, 1967; Kunze and Prasad, 1976).

These variables relate directly to the optimal moisture content during harvest and maximum paddy yield (Berrio and Cueva-Perez, 1989; Dilday, 1989; Seetanum and De Detta, 1973). Above the required harvest moisture, high quantities of underdeveloped kernels reduce milling quality, and below the accepted harvest moisture, grain fissuring occur leading to high breakages (Juliano, 1993).

Research has shown that, to attain optimum milling quality as well as high grain yields, paddy must be planted and harvested at accepted physiological maturity (Ali *et al*., 2000). For rain-fed production system, if the crop is planted too early for harvesting to coincide with the high humidity, the initial growth phase my not get adequate soil moisture for development. When planted late and harvested too early (immature), breakage during milling is high as a result of the high amount of thin, light, unfilled and chalky kernels that are very fragile. If paddy is harvested very late, breakage during milling is high as a result of a condition referred to as 'sun checking', which is the development of fissures in the individual kernels. Knowledge on appropriate timing of planting, harvesting and storage is therefore pertinent in breakages reduction.

Use of appropriate nitrogen application regimes has also been postulated to enhance hardness and reduce breakages in rice (Faraji *et al*., 2013). Optimum application of nitrogen results in higher yields (Firouzi, 2015). Across northern Ghana, the currently recommended practice is two split application of nitrogen at the recommended rate. Two split application has been found to result in inefficient use of nitrogen as most of the nitrogen applied are not available at the grain filling stage when the plant requires the nitrogen nutrient most (Tari and Amiri, 2015), resulting in less filled grains that are thin, dry-out readily and are susceptible to cracking (Rehman *et al*., 2013). Finding adequate nitrogen application regime for perfumed rice production will therefore result in the production of grains that are well filled, thick to resist easy drying and are resistant to cracking.

Across northern Ghana, knowledge on the right combination of paddy production systems that enables production of market - driven, perfumed rice that can also be straight-milled in large volumes and under rain-fed conditions is limited. There is the need therefore to undertake a research to identify suitable agronomic production techniques and appropriate timing regimes that will reduce cracking and enable straight milling of aromatic paddy to help meet the market demand.

1.2 Objectives

The objective in this study is to help reduce crackness in perfumed, straight-milled rain-fed rice production system.

Specific objectives designed to achieve this goal are:

1. To identify the best crack-resistant aromatic rice variety in northern Ghana.
2. To identify the right planting time in the cropping season that ensures adequate maturity of perfumed rice and which is associated with low cracking.
3. To identify the best split application regime for N which is associated with high yield but low cracking during milling.
4. To identify the best harvesting time in the cropping season that ensures adequate maturity of perfumed rice and which is associated with low cracking.
5. To identify the effect of Julian day of harvest and duration of storage on cracking in perfumed rice.
6. To identify the best interaction split application regime for N, planting time, harvesting time and duration of storage (before milling) which is associated with low cracking in perfumed rice varieties.

CHAPTER TWO

2.0 Literature review

2.1 Botany of rice

Rice is a member of *Oryza* genus and *Gramineae* family (Kirk, 1998). There are 25 species, of which 23 are wild species and two; *O. sativa* and *O. glaberrima* are domesticated (Morishima, 1984; Vaughan, 1994; Brar and Khush, 2003). *O. sativa* is a self-pollinated crop with a degree of out-crossing (< 0.5%). Both cultivated and wild rice varieties can be pollinated by wind, but a few of these varieties have aromatic flowers that attract bees (Oka, 1988). A natural greater out- crossing is noted when there are honey bees (Gealy *et al*., 2003).

Rice pollen is short-lived, with most pollen grains losing viability shortly. In another study conducted by Koga *et al*. (1969), he reported that, about 90% of the pollen grains were found to be viable for only four minutes, and the viability decreased approximately by 33% between the fifth and eighth minutes after shedding. This confirms his earlier statement that, both morphology and pollen viability is affected by the shedding and period after shedding respectively. Fertilization of rice takes place in the spikelet. It is completed within a period of six hours. To initiate double fertilization, only one pollen grain reaches the ovule. Rice is very sensitive to temperature, most especially to cold temperatures during fertilization (McDonald, 1979).

2.2 Morphology of the rice plant

Rice crop is an annual grass, which has round and hollow jointed culms. It is a semi aquatic plant and consists of parenchyma tissues (Agropedia, 2009). Rice is the only cereal crop that grows in both flooded and non-flooded soils. The crop is cultivated under several geographic and environmental conditions. Rice is cultivated in about five continents. The conspicuous parts of the matured rice plant are roots, stem, leaves, leaf sheath, panicles and tillers. The presence of parenchyma cells on leaf enables the diffusion of oxygen from aerial parts downward to the roots (McDonald, 1979; Agropedia, 2009).

2.2.1 Rice roots

The roots constitute the underground portion of the plant. It provides anchorage for stability, take food and water from the soil. The rice roots are fibrous and consist of rootlets and root hairs (Agriquest, 2012). The root connects upward to the plant stem.

2.2.2 Rice stems

The stem consists of sequence of nodes and internodes. The internodes are hollow, with a smooth surface. According to Wopereis *et al*. (2009), the primary role of the stem is to transport water and nutrient and also to make available air to the roots. The stem extends to the panicles.

2.2.3 Rice panicle

Panicles are composed of the primary ramifications that support secondary branches and pedicels that support the spikelets. The amount of main and secondary ramifications is dependent on species and environment. A well-developed single panicle can bear about 500 spikelets (Xing *et al.,* 2008; Wopereis *et al*., 2009). The panicle is connected to both the spikelet and the leaf.

2.2.4 Rice leaves

Rice shows alternate leaves arrangement on the stem, with one leaf for each node. The last leaf wrapping the panicle is the flag leaf. Growth and development are driven by the leaves. They utilize solar radiation and self-embedded chlorophyll to produce carbohydrates, through photosynthesis. Gaseous exchange takes place in the leaves through the stomatal pores and is efficient depending on the rate of stomatal opening and closure. Leaf shedding and stomatal closure is enhanced as a drought tolerance mechanism. The rice plant transpires through its leaves. Architecture of the leaf depends on the variety and environmental conditions prevailing especially, availability of moisture (Wopereis *et al.*, 2009). The sheath is the component of the leaf wrapping the tillers.

2.2.5 Rice tillers

The tiller is the secondary stem and can generate tertiary tillers. The group of tillers generated by a single rice plant is known as a rice hill. Wopereis *et al.*, (2009), stated that, ability of the rice crop to tiller effectively can be influenced by variety, as well as environmental or growing conditions and timely agronomic or crop management practices. Tillers bears the rice grains, more tillers mean more yield (Li *et al.*, 2003). Tillers in rice show as soon the rice crop is self-supporting (Maclean, 2013).

2.3 Rice life cycle

There are three phases in the rice life cycle.

These phases are:

2.3.1 Vegetative phase

The vegetative phase includes germination, seedling, tillering, internode elongation and panicle initiation.

2.3.1.1 Germination

Sufficient moisture imbibition is the prerequisites for embryo germination in rice. It indicates the beginning of metabolic activity and extends to the stage from the emergence of the coleoptile or the radicle to the emergence of the first leaf (McDonald, 1979; Agropedia, 2009; Wopereis *et al.*, 2009).

2.3.1.2 Seedling

This is the period that follows germination and takes about 14 days. During this stage, the young seedling is essentially fed by the endosperm food reserve. The formation of leaves follows a ratio of one leaf per three or four days (Agropedia, 2009; Wopereis *et* *al*., 2009). The seedling stage ends with the formation of the fifth leaf. Roots are also produced during the seedling stage (Wopereis *et al*., 2009).

2.3.1.3 Tillering

Though roots are produced during the seedling period, tillering also begins. The stage coincides with fifth leaf appearing. The number of tillers increases until it reaches highest tillering (Wopereis *et al*., 2009).

2.3.1.4 Internode elongation

The internodes of the plant begin to develop at the end of the tillering stage leading to an increase in plant height.

2.3.1.5 Panicle initiation

This stage is characterized by the appearance of the panicle. The young panicle that emerges inside the bottom of the last node become visible only 10 days after it is formed (Agropedia, 2009; Wopereis *et al*., 2009).

2.3.2 Reproductive phase

The reproductive phase includes panicle development, heading and flowering.

2.3.2.1 Panicle development

The swelling of the bottom of the panicle leaf marks the beginning of panicle development stage. The bottom swelling results from panicle growing upwards inside the stem. The panicle develops to the top of the stem after initiation causing the stem to elongate. The flower organs develop and the panicle continues to grow until it reaches its final size before the flag leaf appears (Wopereis *et al.*, 2009).

2.3.2.2 Heading and flowering

Heading stage begins when the panicle emerges from the bottom of the flag leaf. The panicle takes two to three weeks to emerge from the stem completely. Flowering begins three days after heading (Agropedia, 2009; Wopereis *et al*., 2009).

2.3.3 Maturity phase

Milk formation, dough formation and the matured grain, marks the maturity phase of rice

2.3.3.1 Milk formation

The ovary swells and the grain grows until attains its optimum size. The grain turns watery and then reaches a milky consistency. The content of the grain is a white liquid that can be squeezed out (Wopereis *et al*., 2009).

2.3.3.2 Dough formation

The milky portion of the grain begins to solidify and then reaches hard dough about fourteen days after flowering (Wopereis *et al.*, 2009). The panicle starts to bend while the colour of the grains changes gradually from greenish to yellowish.

2.3.3.3 Matured grain

In the matured grain stage, the grain in the panicles attains a change in colour from yellowish to deep yellow. When the grain reaches its optimum size and weight, it is matured. The grain hardens and panicle becomes droopy in appearance (Wopereis *et al*., 2009).

2.4 Pest and diseases rice

An unpredictable challenge prevails in the growth of new fields for rice cultivation and intensification, among which pest and diseases are most probable to occur. The growing occurrence of rice pest and disease are ascribed to new extremely susceptible foreign rice varieties mostly from Asia (Thresh *et al*., 2001). However, Africa has some indigenous *Oryza* (including *O. barthii*, *O. longistaminata* and *O. glaberrima*) species that can be used as prospective sources of resistance to many rice diseases especially bacterial leaf blight (Vikal *et al*., 2007). Despite chemical control measures to boost agricultural output, 20 – 40 % of production is still lost to pests and diseases (Obeng-Ofori, 1998; Diagne *et al*., 2013).

Rice grows in diverse soils and climates but it is best adapted to warm, humid environments. In such environment, pest and diseases are more prolific as compared to a cooler and dryer environment (Candole *et al*., 2000). Again, in environment where year-round continuous cropping is practiced, without integrated pests and diseases management programme, there are overlapping pest and disease generations throughout the year (Candole *et al*., 2000).

Rice diseases are caused primarily by fungi, bacteria or viruses. Stunting is one of the symptoms; others are colour changes, wilting or abnormal development of certain organs, delayed maturity, less tillering, unfilled grain, low yield and high breakages/ crackness during milling. These symptoms can be found in all the organs of the plant. Rice pests include weeds, pathogens, insects, nematode, rodents, and birds (Thanh and Singh, 2006). Rice production has increased considerably in the past; however, biotic factors especially diseases, non- parasitic weeds, bird damage and insect pest cause substantial losses annually to the rice crop (Nutsugah, 1997b). Many rice disease and insect pest occur sporadically and can result in total crop loss. Identification and development of varieties resistant and tolerant to diseases and insect pest would, therefore, be of considerable benefit in stabilizing rice production in Northern Ghana (Nutsugah, 1997a). Diseases such as rice blast or sheath blight can cause milling quality reductions (Candole *et al*., 2000).

2.5 Rice production in Ghana

Mobil and Okran (1985) reported that, rice has been grown for a long time in Ghana but Ghana's domestic rice production has been continuously lower than its consumption requirements. In reference to production area and yield for rice in Ghana for the period 2000-2010. It was reported that, rice production increased from 0.09 and 0.16 million hectares while yields fluctuated between 1.7 and 2.7 tonnes per hectare. It however appears that from 2007, rice production has been on the increase with 2010 production levels being more than double 2007 levels (from 185 300 tonnes in 2007 to

491 600 tonnes in 2010) with average annual growth of more than 15 percent over the period 2005-2010, despite the production drop experienced in 2007 (MOFA, 2010).

The government therefore imports up to 200% of rice to compensate for the brief supply decline. This drains the country of it scarce foreign exchange (Dogbe, 1996). Between 1989 and 1994, after falling from 48.3% between 1970 and 1974, Ghana was noted to be only 15.1% self-sufficient in rice production (Oteng, 1994). This implies that Ghana still need enormous imports to compliment the local demand deficit (Manful *et al.*, 1998). Obeng (1994) reported that rice cultivation in Ghana is undertaken in three different ecologies: lowland rain-fed ecology, which includes rice planted in the receding waters of the Volta and other rivers (78% of production); upland rain-fed ecology (6%), and irrigated ecology (16%) (MOFA, 2010). Lowland production is mainly practiced by women in lowland areas, and is often done without supplementary irrigation. Rain-fed rice production contributes 84% of total current production, generating average paddy yields of 1.0 - 2.4 metric tonnes (MT) per hectare while irrigated production accounts for just about 16 percent of production but produces the highest average paddy yields of 4.5 MT per hectare (MOFA, 2010). Rain-fed lands and swampy areas producers are able to plant rice in two seasons as the rainfall pattern in these areas is bimodal in nature from between March to July and September to November.

2.6 Socioeconomic importance of rice

Shilpa (1996) reported that, global rice' socioeconomic use is great; the main among them are; staple food for human and animal nutrition. Countries also profit from rice production by getting foreign exchange and medicine. The grain products include: flakes, rice milk, and the extended uses of rice include rice husk for fuel, rice bran for animals feed, broken rice used as snacks beverage (Shilpa, 1996).

2.7 Medicinal value of rice

There is no proof of any toxicity or pathogenicity related to the use of rice as a human food crop (FAO, 2004). However, there may be low toxicity levels in the antinutrients including phytic acid, trypsin inhibitor, hemagglutinins (lectins) present in the bran portion (FAO, 2004). Rice is regarded to be acrid, oleaginous, tonic, aphrodisiac, fattening, diuretic, and useful in gall bladder (Das and Oudhia, 2000). In Red yeast rice is used in Chinese medicine to enhance blood circulation, soothe stomach upset, and boost spleen function (FAO, 2004). Also the rice straw used as animal feed in many parts of the world (Jackson, 1978; Drake *et al.*, 2002; FAO, 2004), has the ability to cause toxicity if fed in large amounts owing to elevated concentrations of oxalates (1 to 2%) in the straw (Jackson, 1978), which can lead to calcium deficiencies if supplements are not supplied (FAO, 2004). Rice is generally, regarded to be small in allergy (Hill *et al.*, 1997).

2.8 Nutritional value of rice

Rice is a staple dietary food that offers immediate energy as carbohydrate is its most significant component. On the other hand, rice is poor in nitrogen substances with only 8% average nitrogen and only negligible 1% fat contents or lipids (Juliano, 1985) and it is regarded as a complete food because of this reason (Juliano and Goddard, 1986). Rice flour is rich in starch and is used to make different foods. It is also used by brewers to create alcoholic malt on some cases.

The degree of milling and polishing determines the amount of nutrients removed (Das and Oudhia, 2000), however, loss of nutrients resulting from milling and polishing is very considerable. Rice bran is one of the richest sources of vitamins, minerals and antioxidant found in nature (Das and Oudhia, 2000). Endosperm cells are thin walled, usually radially elongated, and packed with amyloplasts comprising compound starch granules and protein bodies (Juliano, 1993).

2.9 Aromatic / perfumed trait of rice

Aromatic rice has become popular because of its aroma (Widjaja *et al.*, 1996). Growing demand for aromatic rice has prompted interest in the growth of local cultivars offering comparable combinations of grain attributes such as texture, cooking characteristics, aroma, and taste. Aroma in rice is primarily associated with the presence of 2-acetyle-1-pyrroline (Lorieux *et al.*, 1996). This compound is strongly linked to the aroma of Basmati and Jasmine types of rice (Lorieux *et al.*, 1996; Widjaja *et al.*, 1996; Yoshihashi *et al.*, 2004; Hien *et al.*, 2006a).

Many other compounds that give aroma in aromatic rice cultivars have also been discovered (Widjaja *et al.* 1996). Aroma detection methods include leaf tissue, smelling grains after heating in water, and reacting with solutions of 1.7% KOH (Sood and Siddiq 1978). Other methods such as identification of 2-acetyle-1-pyrroline, using Gas Chromatography Mass Spectrometry Selected Ion Monitoring (GC-MS-SIM) are also available (Hien *et al*., 2006b; Lorieux *et al*., 1996; Widjaja *et al*., 1996; Yoshihashi *et al*., 2004). Molecular markers, such as Single Nucleotide Polymorphism (SNP) and Simple Sequence Repeats (SSR) that are genetically linked to aroma have also been developed for the selection of aromatic rice (Cordeiro *et al*., 2002; Jin *et al*., 2003). The accessibility of the sequence of the rice genome offered the chance to discover the gene responsible for rice aroma; this was accomplished by comparing the sequence of aromatic and non- aromatic genotypes (Goff *et al*., 2002; IRGSP 2005).

2.10 Nitrogen requirement and application

Nitrogen is the most important component in determining rice's yield potential (Cassman and Pingali**,** 1995; Cassman *et al*., 1996). Nitrogen is required at early and mid tillering to increase number of panicles. At the reproductive and maturing phases, Nitrogen is also required to enhance the number of spikelets per plant and the percentage of filled spikelets (De Datta *et al*., 1986). The estimated quantity of nitrogen removal for the production of one tonne of rough rice, including straw, ranges from16-17 kg (Dobermann and Fairhurst, 2000; Sahrawat, 2000). The efficiency of nitrogen uptake varies from 20 to 60% depending on the prevailing conditions (soil type, water, pH and soil temperature), doses and modes of supply (split or not) and crop varieties

(Perez *et al*., 1996). The milling yield was hypothesized to be linked to the soil's nitrogen supply ability, which determines the protein content of the grain (Perez *et al*., 1996). Application of nitrogen fertilizer at various phases from panicle initiation, heading, flowering to grain filling has all been shown to significantly boost protein content (Nangju and De Datta, 1970; Taira, 1970; Nagarajah *et al*., 1975; Vaughan *et al*., 1980; Perez *et al*., 1990; Perez *et al*., 1996; Souza *et al*., 1999; Leesawatwong *et al*., 2004, 2005) as well as protein related traits like the milled rice rate, head rice rate (Wopereis-Pura *et al*., 2002; Leesawatwong *et al*., 2005) and translucency (Perez *et al*., 1990, 1996). In addition, application of nitrogen reduced the amylose content of rice kernel, while the protein content was not substantially affected (Bahmaniar and Ranjbar, 2007), and protein content is also correlated to grain milling efficiency (Leesawatwong *et al*., 2005).

The quality of the grain is not only dependent on cultivars but also on crop management practices (Leesawatwong *et al*., 2005). Application of N has been reported as a prevalent crop management practice that influence the grain quality (Wopereis-Pura *et al*., 2002; Leesawatwong *et al*., 2005). The milling quality of rice can also be enhanced by applying nitrogen properly (Wopereis-Pura *et al*., 2002; Leesawatwong *et al*., 2005). Nitrogen helps to increase protein matrix packaging between endosperm starches in rice grains, and grain protein makes it more resistant to cracking and breakage during processing (Blumenthal *et al*., 2008).

2.11 Effect of variety on milling of rice

Different rice varieties react differently to cracking in the grains because of water absorption variations (Jodari, 1996). The milled rice yield relies not only on the crop management and variety, but also on the management of postharvest activities and the specific drying conditions used (Brooker *et al.*, 1992). A combination of different varieties in s sample or bulk of paddy grains generally results in decreased milling ability, excessive breakages and lower milling and head rice yield. Past research identified important parameters in long– grain varieties that cause milled rice kernel breakages. Adu - Kwarteng *et al*. (2003) discovered that some lines of the new varieties had excellent grain size and shape, excellent endosperm appearance, greater amylose content and milling quality.

Jodari (1996) noted that, understanding and providing data on the rice varieties with comparable grain features would help to decrease losses in milling and quality, thereby leading to improved handling and storage. The length of the grain in rice plays a major function. Wan (2008) reported that, it helped in determining the quality of milling and grain appearance. The various characteristic of rice quality according to Webb (1985), include hull and pericarp colour, grain size and shape, grain weight, uniformity, appearance, milling properties and purity.

2.12 Effect of planting date on milling yield

The date of planting has an important role in rice grain quality and milling yield (Sha and Linscombe, 2007). Planting date is different in various agro ecological conditions. Sha and Linscombe (2007) reports showed that, planting date does not have significant effect on 1000 grains weight but rather, one of important indices that had effect on photosynthetic ability is leaf area index. With delaying in planting, harvest index which include milling yield would be decreased (Miller *et al*., 1991).

2.13 Effect of climatic factors on milling yield

Getting to the harvesting season, the climate in rice production areas are dominated by sunshine and relatively high temperature during the day and high relative humidity at night. In such conditions, the grain loses moisture relatively quickly during the day and in the night reabsorb significant amount of moisture. The moisture gradient creates differential tension and causes fissures in the grains resulting in breakages of the grains during milling (Hashemi *et al*., 2008). Akowuah *et al*. (2012) reported that, grain cracking can occur in the field prior to harvesting, processing and storage. Understanding the effects of rice crackness is very significant to the domestic rice industry in optimizing grain moisture and quality of milled rice. Mechanical effect and excessive-exposure of paddy to alternating temperature and moisture conditions subject the paddy to the cracks development (Dong and Zhihuai, 2003). The occurrence of tensile cracks is proportional to the amount of the temperature and moisture gradient established when heat is applied to wet grains (Abe *et al*., 2010).

Fissured kernels, according to Abe *et al*. (2010) contributed to breakage of rice grains and hence resulted in decrease of milling recovery.

2.14 Effect of grain moisture on milling yield

Generally, it is appropriate to harvest paddy when the average grain moisture is below 18% (Cnossen *et al*., 2003). Ilieva *et al*. (2009) noted that, the best period to conduct harvesting harvest is when the grain moisture is between 18 and 20%.

In research of Bautista *et al*. (2009), the optimum harvest moisture recommended for long - grain varieties ranged from 18 to 22% and 19 to 20% for short - grain cultivars. Similar results had been established earlier by Bautista and Siebenmorgen, 2008. Siebenmorgen *et al*. (2007) reported that, head rice yield is a quadratic function of grain moisture at harvest, which implies that there is optimum harvest moisture content to enhance head rice yield and milling quality, and this information cannot be ignored.

Harvest moisture, paddy postharvest handling and other factors that have effect on yield and quality of paddy have been studied by many authors including (Thompson *et al*., 1990; Thompson and Mutters, 2006; Akowuah, *et al*., 2012; Saeed and Mohammad, 2013). In all these studies, mainly, milling yield increases with optimum moisture and reduces when the rice was harvested with lower or higher harvest moisture.

All the past studies emphasized that, the information about the effect of moisture at harvest and storage duration after harvest on milling quality of paddy is very important.

This information helps in defining the best recommendations before and after harvest in order to maintain high milling quality of rice varieties. Cnossen *et al*., (2003) indicated that breakage in the grain occurs because the kernels have subsequently been weakened by stress cracks (fissures) caused by rapid moisture adsorption or desorption. Fissures occur when the matured grain is subjected to fluctuating temperature and moisture conditions in the field, which leads to absorption and desorption of moisture by the rice kernels (Kunze, 1979; Calderwood *et al*., 1980; Lu *et al*., 1994; Kunze, 2001), and these were postulated to be the main reason for the cracks (fissures). The paddy kernels with large fissures break easily during harvesting and processing.

2.15 Effect of rice maturity and harvesting conditions on milling yield

Generally, a healthy rice seedling grows for about 4-5 months before maturity (Ali *et al*., 2000). The rice plants grow rapidly, ultimately reaching a height of about 90 cm. At maturity, grains appear on the top of the plant in long panicles, become tan brown and ready to be harvested. Also, kernels on a panicle will exist at very different moisture contents (MCs), representing various maturity and kernel strength levels (Bautista and Siebenmorgen, 2005). If the brown hull still covers the rice, it is known as paddy. Most of the previous studies on ideal moisture content for rice cultivation has shown that, the output of head rice yield (whole grain milled rice yield) is adversely influenced by the harvesting of rice with moisture content that is either too high or too low (Geng *et al*., 1984; Siebenmorgen *et al*., 1992; Jodari and Linscombe, 1996). This has been confirmed by many authors. Methods of harvesting rice depends on the size of the operation and the amount of mechanization available. Harvesting could be done either by hand or a machine. Due to the existence of immature kernels, early harvesting can decrease the field and head rice yield of paddy. Late harvesting can decrease rice yield due to grain shattering and lodging. Therefore, knowledge on optimum time and moisture for harvesting should be determined and included in the harvesting plan. Harvesting sequence of paddy normally includes cutting, threshing, cleaning, and bagging for transport to drying areas. Barber (1972) and Juliano (1985) reported that, ageing rice enhanced its hydration and reduce milling yield. Again, the incidence of crop lodging at harvest time is a unique factor that can have a significant effect on the milling yield of harvested paddy. Lodging in cereal crops has been defined as the state of permanent displacement of the stems from their upright position (Somado *et al*., 2008). In relation to the prospective decrease in the quantity of yield actually retrieved by the harvester in the field, the extension of lodging in the field coupled with the duration of lodged plant in the field, along with field circumstances and climate during that moment may have an important effect on the resulting milling quality of the harvested paddy (Salassi *et al*., 2013). Milling output reduction is even higher when there are rains between ripening and harvesting, particularly when the humidity decreases to 15% or less before rain (Siebenmorgen *et al*., 1992). Delayed harvest in rainy weather and the crop lodging often leads to grain sprouting on the panicles. During harvesting season, the incidence of heavy rains can even generate rice mould contamination (Juliano, 1993). With harvesting recommendations, Somado *et al*. (2008) reechoed the yellow-brown criterion and adds that harvest of NERICA varieties should occur when at least 80% of the upper portion of the main panicle is straw-coloured.

Rhodes (2005) recommends harvesting early in the morning or after sunset as compared to mid-afternoon, especially during the harmattan period, which may cause shattering. Rice at a moisture content of > 24% begins to produce ethanol "within hours after harvest" (Rhodes, 2005). Rhodes (2005) elaborated that, microbial activity rapidly leads to odours and a reduction in flavour. Nothing can be done to the grain after harvest, thus, the quality of rice grain is set at harvest. Storage cannot enhance grain quality, but storage circumstances and length can have significant adverse impact on the paddy's milling quality.

Conclusion

Rice is an important cereal crop serving as food for a many people (Jittanit *et al*., 2010). During the milling process, its kernel breakage is a significant problem in all rice-producing nations particularly, the developing ones. Milling quality has always been a significant area of studies in both rice variety development works as well as research on the effects of alternative rice production methods and the effectiveness of inputs on yield. Important plant variety features assessed in the release of fresh commercial rice cultivars were the expected yield and yield component stability (Linscombe *et al*., 2000, 2006; Sha *et al*., 2006; Blanche *et al*., 2011).

Research assessing factors affecting the output of rice milling yield included cultivar and planting date (Sha and Linscombe, 2007; Sha *et al*., 2007; Blanche and Linscombe, 2009; Blanche *et al*., 2009), crop management practices and nitrogen application rates (Ottis and Talbert, 2005; Walker, 2006; Harrell and Blanche, 2010), climatic conditions (Liu *et al*., 2013), soil moisture management during the grain-filling period (Zhang *et al*., 2008) and irrigation water availability (Zeng and Shannon, 2000). Traditional pre-harvest variables recognized to affect rice milling yield included time of planting, irrigation and N rates, cultivar choice and moisture at harvest (Siebenmorgen *et al*., 2013). Research also identified ranges for the optimum moisture content in rice harvesting to optimize the output of head rice milling yield (Juliano and Perez, 1993; Siebenmorgen *et al*., 2007). It is appropriate to indicated that, the yield and milling quality of aromatic rice, obtained by paddy processing determines the income of all the actors in the rice value chain especially, the smallholder farmers. All actors directly depend on yield and paddy milling quality. For maximum yield and milling recovery of paddy and white aromatic rice, the most essential factors are the planting date, soil N supplying capacity, and harvesting as well as postharvest paddy storage conditions. Arora *et al*. (1973), Siebenmorgen *et al*. (1992), Cnossen *et al*. (2003) and Zhang *et al*. (2003) reiterated that, the typical value of broken rice is about one third to one half of that of whole rice. The milling output is essentially sensitive to the drying mode and is generally used to evaluate the rice milling system's success or failure (Izadifar and Mowla, 2003).

CHAPTER THREE

3.0 Materials and methods

The study comprised of two components: a field work from planting to harvest and laboratory determination of cracking.

3.1 Field location

3.1.1 Site description

The field experiment was conducted during the rainy season from April to October 2016 in three geographically distinct rice production locations (Kubori, Yagaba, Soo) in the Mamprugu Moagduri district. The three locations served as replications for the experiment. The district is within longitudes 0°35'W and 1°45'W and Latitude 9°55'N and 10°35'N. The location of the three experimental sites lies between (N 10.17609°,W 001. 29434, 140 m), (N 10. 18252°, W 001. 29143, 138 m) and (N 10. 18249°, W 001. 29086, 140 m) respectively. The district shares boundaries with North Gonja, Kumbungu, West Mamprusi, Sisala East and Builsa South Districts (MOFA, 2010).

3.1.2 Climate

The district lies within the savannah climatic belt consisting of tropical, warm and semi-arid with a short unimodal rainy season followed by a long dry season (Kugbe *et al.,* 2012). Average annual rainfall is between 1000mm and 1400mm.The rains occur between April and October. The highest rainfall is recorded between July and October. Floods happen during the peak period from November to April after which there is an extended harmattan season. Temperatures are usually high the whole year, with the hottest between February and March. Average monthly temperature is between 25.5ºC and 35.0ºC (MOFA, 2010).

High humidity and sunshine with intense thunderstorms occurs in the rainy season. Dry north-easterly trade winds from November to February and high sunshine from March to May characterize the dry/ harmattan season (MOFA, 2010). The long period of dryness makes the district very vulnerable and susceptible to bush fires (Kugbe *et al.*, 2012), which imposes a barrier on continuous crop production whiles limiting the cropping season.

3.1.3 Relief and drainage

Middle Voltain rocks, which are usually appropriate for rural water supply, made up the district geology. It is mainly characterized by a flat and undulating topography. The most significant watershed in the district is the White Volta and its tributaries including Sissili, Goriba and the Kulpawn rivers. Along the valleys of these rivers are large arable lands, excellent for the cultivation of rice and other cereals (MOFA, 2010).

3.1.4 Soil and vegetation

Soils in the district are developed under the Savannah vegetation. Alluvial soils, which are also appropriate for rice production, are quite vast around the valleys. In the district, there is significant soil erosion owing to the bad farming methods and widespread bush burning. The natural vegetation is categorized as Guinea Savannah Woodland, which consist of trees of differing dimensions and density, growing over a scattered covering of perennial grasses and shrubs (MOFA, 2010).

3.2 Source of seeds

Four perfume rice foundation seed varieties namely **Gbewaa, AGRA, Exbaika and Perfume Irrigated** were received from CSIR-Savannah Agricultural Research Institute in Nyankpala.

3.3 Experimental design and treatments

The field experiment was a 4 x 3 x 6 factorial laid in a Randomized Complete Block Design with 4 rice varieties, 3 split nitrogen application regimes, and 6 planting dates. The four rice varieties were combined with three nitrogen application regimes and six planting dates. Nitrogen was applied in all cases at a rate of 100 kg/ha using NPK as basal and urea as top dressing. The N split application regimes were:

1. N applied ½ at early tillering (Basal) + ½ at panicle differentiation (6 weeks after first application).
2. N applied ½ at early tillering (Basal) + ¼ at panicle differentiation (6 weeks after first application) + ¼ at grain filling stage (6 Weeks after second application).
3. N applied ¼ at early tillering (Basal) + ¼ at panicle differentiation (6 weeks after first application) +¼ at heading (3 Weeks after second application) + ¼ at grain filling stage (3 Weeks after third application).

The six planting dates were:

1. First planting date (First week of July)
2. Second planting date (Second week of July)
3. Third planting date (Third week of July)
4. Fourth Planting date (Fourth week of July)
5. Fifth planting date (First week of August)
6. Sixth planting date (Second week of August)

There were 72 treatment plots on each block/field. Each plot measured 5 m x 5 m and with the three geographic sites serving as the replicates. There were two hundred and sixteen (216) experimental plots in totality. A one (1) meter alley was left between plots. At harvest, each experimental plot was divided into six (6) parts, for six (6) staggered harvesting times, bringing total treatments at time of harvest to 432 (72 x 6) treatments.

3.4 Field activities

3.4.1 Soil sampling

Soil samples for determination of soil available N and P were obtained from the upper soil surface layer (0 - 20 cm) using a 5cm diameter soil auger. The soil samples were collected prior to ploughing using the simple random method. Soil samples were taken from twenty-five different spots in each experimental location using an auger and the soil was bulked together to get one composite sample. The composite sample was thoroughly mixed and divided into five parts. One of the five divided parts was taken to the laboratory to determine the initial soil properties.

3.4.2 Field preparation and layout

The field was ploughed and harrowed using a tractor. The experimental field was demarcated and bounded prior to the experimental setup. The bounding was done to block fertilizer drift from one plot to another and also to conserve moisture in the experimental plots. Each experimental plot measured 30 m x 5 m (150 m^2) prior to maturity, giving a plot size of 5 m x 5m at the staggered harvest time. One (1) meter alley was left between plots. The land area of each experimental location was 13392 m^2 ((30 m + 1 m alley) x (5 m + 1 m alley) x 72), and the total land area of the three locations was 40176 m^2.

3.4.3 Sowing

A seed rate of 40 kg/ha was used for the four (4) perfumed rice varieties: Agra rice, Jasmin (Gbewaa), Exbaika and Perfumed Irrigated. The seeds were sown in 0.20 m row spacing and planting distance with a depth of about 2 – 4 cm. These varieties were sown directly at 1 weekly planting interval for six (6) planting dates.

3.4.4 Weed management

On the third day after sowing, pre-emergence herbicide Bispyribac Sodium 400 G/L SC (Bisonrice) was applied to kill all emerging weeds and weed seed stock to avoid early competition during seed emergence and germination. The first manual weeding was done thirty (30) days after sowing and the second manual weeding was done sixty (60) days after sowing.

3.4.5 Fertilizer application

Phosphorus (P) and potassium (K) were applied as basal fertilizers at rates of 50 kg/ha P_2O_5 and K_2O each using NPK 15:15:15, triple superphosphate (TSP) and muriate of potash (MoP). The TSP and MoP were used to supplement P and K fertilizers under treatments where first NPK application was given less than 50 kg/ha of P and K.

3.5. Field measurement

The following plant parameters were measured on the field.

3.5.1 Julian day of planting

The day the paddy was planted on each plot, counting from first January.

3.5.2 Days to 50% flowering

The Days to 50% flowering was measured by counting the number of days from planting to when half (50%) of the rice plants on each plot produced spikelets. This was recorded in days.

3.5.3 Total tiller count

An effective tiller was considered to be one which bears a panicle on which the grains will ripe fully (Karen and Nathan, 2013). Vegetative tiller was considered to be one which does not bear a panicle on which the grains will ripe fully. The total number of tiller per plant was taken by counting.

3.5.4 Number of panicles per stand

The number of panicles per stand was taken by counting the total number of panicles available per hill.

3.5.5 Number of days to harvest

The number of days to harvest was measured by counting the number of days from germination to when the paddy was harvested.

3.5.6 Julian day of harvesting

It is the day the paddy was harvested on each treatment plot. This date was recorded from which number of days to harvest was estimated.

3.5.7 Harvesting

The first of staggered harvesting was done one (1) week prior to the recommended harvesting date for each variety. Each treatment plot of 30 m x 5 m was divided into six sub plots of 5 m x 5 m. Error due to border effect was reduced by allowing a one (1) meter distance between the sub plots. The six sub plots were harvested on six harvesting days at one (1) weekly interval.

3.6 Crack determination

3.6.1 Laboratory location

Laboratory experiments were conducted from October 2016 to May 2017 to determine the level of cracks in the harvested paddy. The laboratory analyses were carried out at the AVNASH Rice Mill laboratory located in Nyankpala. The Avnash Rice Mill is considered to be one of the largest rice milling facilities in Africa.

Parameters determined include: yield, percentage grain moisture, number of days of storage before milling and percentage paddy cracking as affected by duration of storage. Processing of samples was done on two days' intervals and began a day after harvesting (to mimick the possible earliest time for transport of paddy from farm to the milling facility). The crack determination process was repeated for six consecutive months.

3.6.2 Yield

The weight of cleaned and dried grains harvested from a unit area was measured by harvesting all the plants in the harvest area of each treatment plot. The harvested paddy was carefully threshed, winnowed and weighed. The grain moisture content was determined immediately with a moisture meter. The grain weight was adjusted to 14% moisture using the relationship below, and according to International Rice Research Institute (2009).

Equation 1: Harvest area

Area (m^2) = width x length ………………………………………………… *equation* 1

Equation 2: Adjustable grain weight (AGW)

AGW = A X W ……………………………………………….………... *equation* 2

Where**:**

A = Adjustable coefficient (0.9995)

W = Weight of harvested grains

Equation 3: Grain yield

$$GY = \frac{(AGW - MC)}{HA} X\ 10 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ equation\ 3$$

Where:

GY= Grain yield

AGW = Adjustable grain weight

MC = Moisture content

HA = Harvest area

The equations were used to determine the yield of rice (IRRI, 2009).

3.6.3 Percentage (%) moisture content

Grain moisture content was determined using an electronic grain moisture tester (Riceter F Series f 501), which measures and reports moisture content in percentage by weight.

3.6.4 Number of days of storage before milling

This was determined by counting the number of days that grains were stored before milling.

3.6.5 Percentage (%) paddy crackness

This was determined by counting the number of cracked paddy and determined as number of grains with cracks from a 100 random paddy grains.

3.6.6 Percentage (%) cracking with duration of storage

This was done by determining the % crackness at a given duration of storage.

3.7 Statistical analysis

Data were analyzed using GENSTAT statistical package (12th edition). Analysis of variance was used and the treatment means were separated using least significant difference (LSD) at 5% probability (Steel and Torrie, 1980).

Correlation between plant growth, yield parameters, post-harvest paddy moisture, duration of storage and paddy crackness were performed to ascertain the relationships between growth, yield, post-harvest conditions and crackness. Where statistically significant correlations existed, linear regression analyses were performed to identify the extent of the relation. Results are presented in tables and graphs.

CHAPTER FOUR

4.0 Results

4.1 Impact of production inputs and timing on growth parameters, grain moisture and yield of rice

Quaternary interaction of variety, nitrogen fertilizer management regime, planting date and harvest cycle did not significantly affect any growth and yield parameter ($p > 0.05$). However, growth and yield parameters of rice were differently affected by interaction of variety, split nitrogen fertilizer management regime, planting date and harvest cycle (Table 1).

Table 1: Factorial significance (p <0.05) **of rice variety (VA), split nitrogen fertilizer management regime (FM), planting date (PD) and harvest cycle (HC) on effective tiller number per stand (TPS), panicle number per stand (PPS), days to fifty percent flowering (DFF), days to maturity, grain moisture (%) and yield of rice (kg/ha)**

	TPS	PPS	DFF	Maturity	Yield	Moisture
PD	**	**	**	-	**	**
VA	**	**	**	**	ns	**
HC	-	-	-	-	**	**
FM	ns	**	*	ns	ns	ns
PD *VA	**	**	**	ns	ns	ns
PD *HC	-	-	-	-	**	**
VA*HC	-	-	-	-	ns	**
PD*FM	**	**	*	ns	ns	ns
VA*FM	**	**	*	**	ns	ns
HC *FM	-	-	-	-	ns	ns
PD*VA * HC	-	-	-	-	ns	ns
``PD*VA* FM	**	**	*	ns	ns	ns
PD *HC * FM	-	-	-	-	ns	ns
VA* HC* FM	-	-	-	-	ns	ns
PD *VA* HC * FM	-	-	-	-	ns	ns

***P < 0.01, *P < 0.05, ^{ns} P > 0.05, - = statistics not applicable due to lack of one factor, HC, which applies only after harvest. For each growth/yield variable (vertical column), factorial combinations were analyzed following the order: quaternary, tertiary, binary and sole factor. Data that showed significant interactions and/or sole factors (shaded yellow) were used for computing bar graphs and for posthoc analyses.*

4.1.1 Impact of production inputs and timing on number of tillers per stand

Tiller number per stand was significantly ($p < 0.05$) influenced by the interaction of fertilizer management regime, planting date and variety (Table 1). Second planting, + Perfume Irrigated + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) recorded the highest value of tiller number per stand (Figure 1).

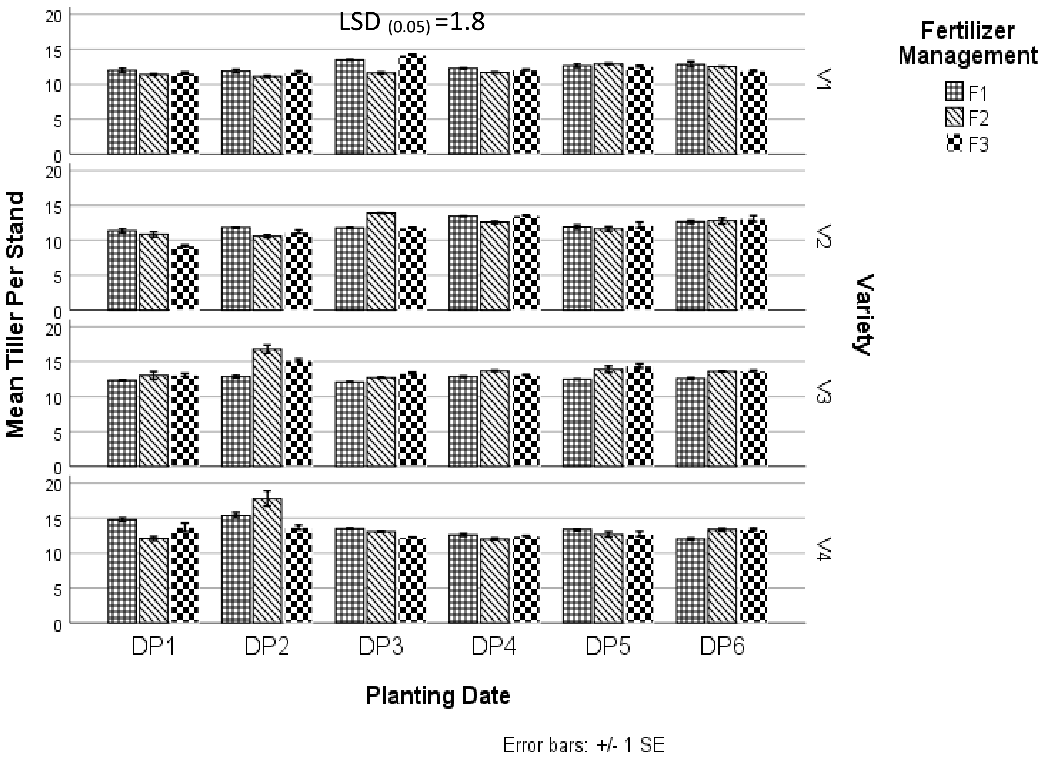

Figure 18: Effect of variety, split nitrogen fertilizer management regime and date of planting on number of tillers per stand of perfumed rice grown in the Northern Savanna Agro ecological zone of Ghana. Bars represent the standard error of mean (SEM). DP1= First planting, DP2= Second planting, DP3= Third planting, DP4= Fourth planting, DP5= Fifth planting, DP6= Sixth planting, V1=Agra, V2= Gbewaa, V3= Exbaika, V4= Perfume Irrigated, F1= Fertilizer management 1, F2= Fertilizer management 2, F3= Fertilizer management 3.

This was followed by Second Planting +Exbaika + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2), Third Planting + Agra + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) and Third Planting + Gbewaa + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) respectively. First Planting + Gbewaa + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) recorded the lowest number of tillers per stand (Figure 1).The treatment with lowest tiller number per stand was followed by First Planting + Perfume Irrigated + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) and First Planting + Exbaika + N applied at rates of ½ at early tillering + ½ at panicle differentiation (F1).

The interaction effect of planting date and variety as well as that of variety and fertilizer management had significant effects ($p < 0.05$) on number of tillers per stand produced. With the interaction of fertilizer management and variety, Perfume Irrigated + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) recorded the highest number of tillers, followed by Exbaika + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2), and Gbewaa + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2), respectively. Gbewaa + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) recorded the lowest value.

With regards to planting date and variety, Second Planting + Perfume Irrigated recorded the highest value, followed by Second Planting + Exbaika. First Planting + Gbewaa recorded the lowest number of tillers per stand followed by Third Planting +

Perfume Irrigated. With the interaction of variety and fertilizer management, Perfume Irrigated + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2). It was followed by Exbaika + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) and Gbewaa + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) respectively. The lowest number of tillers per stand was recorded by Gbewaa + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3), followed by Perfume Irrigated + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3), Perfume Irrigated + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) and Perfume Irrigated + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3).

The main effect of variety and that of planting date as sole factors also had significant effect ($p < 0.05$) on tiller per stand whilst sole application of fertilizer management had no significant influence ($p > 0.05$) on tiller per stand.

4.1.2 Impact of production inputs and timing on number of panicles per stand

Number of panicles produced per stand was significantly ($p < 0.05$) influenced by the interaction of planting date, variety and fertilizer management (Table 1).

With the interaction of planting date, fertilizer management and variety, Second Planting + Exbaika + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) recorded the highest number of panicle per stand, followed by Second Planting + Exbaika + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) which was at par with Second Planting + Perfume Irrigated + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2), Third Planting + Agra + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) and Fourth Planting + Gbewaa + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) (Figure 2).

The lowest number of panicle per stand was recorded by First Planting + Perfume Irrigated + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3). It was followed by First Planting + Gbewaa + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) which was similar to Third Planting + Perfume Irrigated + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3), Second Planting + Gbewaa + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2), Sixth Planting + Perfume Irrigated + N applied at rates of ½ at early tillering + ½ at panicle differentiation (F1) and First Planting + Agra + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2).

With the interaction of Fertilizer management and planting date, Second Planting + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) produced the highest panicle per stand. It was followed by Exbaika + N applied at rates of ½ at early tillering + ½ at panicle differentiation (F1), which was at par with Agra + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3), Perfume Irrigated + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2), and Gbewaa + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3).

The lowest number of panicle per stand was recorded by Exbaika + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3), followed by Perfume Irrigated + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3).

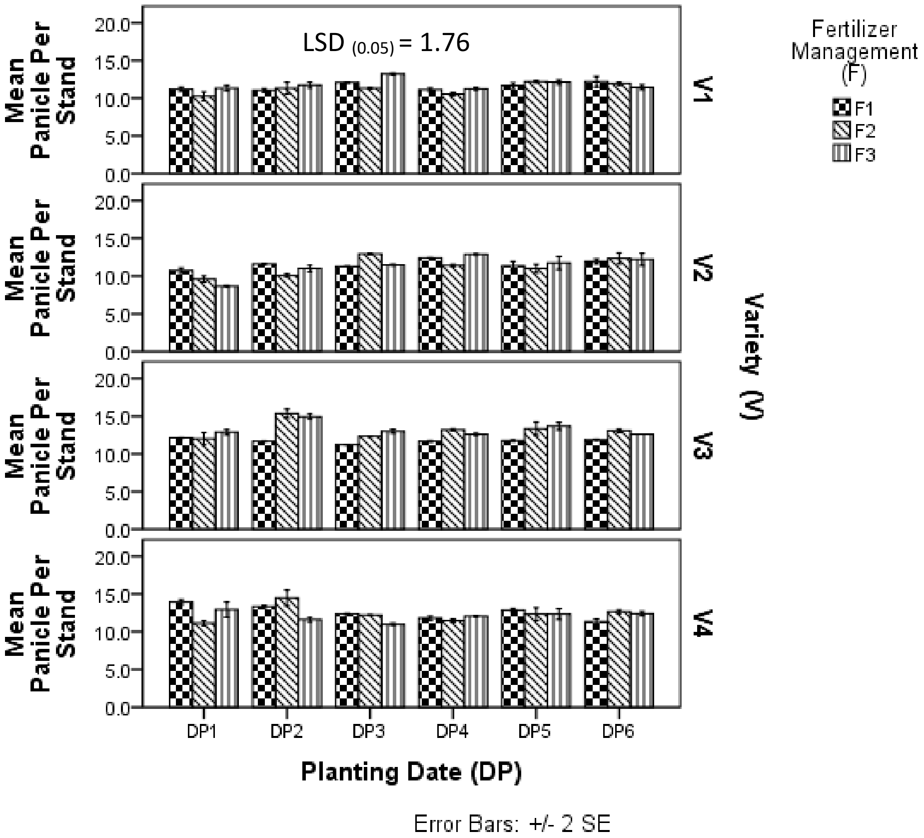

Figure 19: Effect of split nitrogen fertilizer management regime, varietyand date of planting on number of panicles per stand of rice grown in the Northern Savanna Agroecological zone of Ghana. Bars represent the standard error of mean (SEM). DP1= First planting, DP2= Second planting, DP3= Third planting, DP4= Fourth planting, DP5= Fifth planting, DP6= Sixth planting, F1= Fertilizer management 1, F2= Fertilizer management 2, F3= Fertilizer management 3, V1 = Agra, V2 = Gbewaa, V3 = Exbaika, V4 = Perfume Irrigated.

4.1.3 Impact of production inputs and timing on number of days to fifty percent (50%) flowering

The interaction of planting date, variety and split nitrogen fertilizer management had significant (*$p<0.05$*) influence on the number of days to 50% flowering (Table 1). Third Planting + Perfume Irrigated + N applied at rates of ½ at early tillering + ½ at panicle differentiation (F1) recorded the longest number of days to 50% (Figure 3), followed by First Planting + Perfume Irrigated + N applied at rates of ½ at early tillering + ½ at panicle differentiation (F1) which was at par with Second Planting + Gbewaa + N applied at rates of ½ at early tillering + ½ at panicle differentiation (F1), Fourth Planting + Gbewaa + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) and Second Planting + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) + Gbewaa. The least number of days to 50% flowering was recorded by First Planting + Exbaika + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3), followed by Second Planting +Exbaika + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) and First Planting + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) respectively.

With the interaction of variety and fertilizer management, Perfume Irrigated + N applied at rates of ½ at early tillering + ½ at panicle differentiation (F1) had the highest number of days to 50% flowering, followed by Gbewaa + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) which was at par with Perfume Irrigated + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3), Perfume Irrigated + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) and Gbewaa + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2).

With the interaction of planting date and fertilizer management, Sixth Planting + N applied at rates of ½ at early tillering + ½ at panicle differentiation (F1) recorded the highest number of days to 50% flowering, followed by Fifth Planting + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) at par with Sixth Planting + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2). The least was recorded by First Planting + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3), followed by Second Planting + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3), First Planting + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) and Second Planting + N applied at rates of ½ at early tillering + ½ at panicle differentiation (F1) respectively.

With regards to the interaction of planting date and variety, First Planting + Perfume Irrigated had the highest days to 50% flowering, followed by Second Planting + Gbewaa also followed by Fifth Planting + Gbewaa which was similar to Third Planting + Gbewaa and Fourth Planting + Gbewaa. The least days to 50% flowering was recorded by Third Planting + Exbaika, followed by Third planting + Agra at par with Second Planting + Agra and First Planting + Agra.

The main effect of variety, fertilizer management and that of planting date as sole factors also had significant effect ($p<0.05$) on Days to 50% flowering.

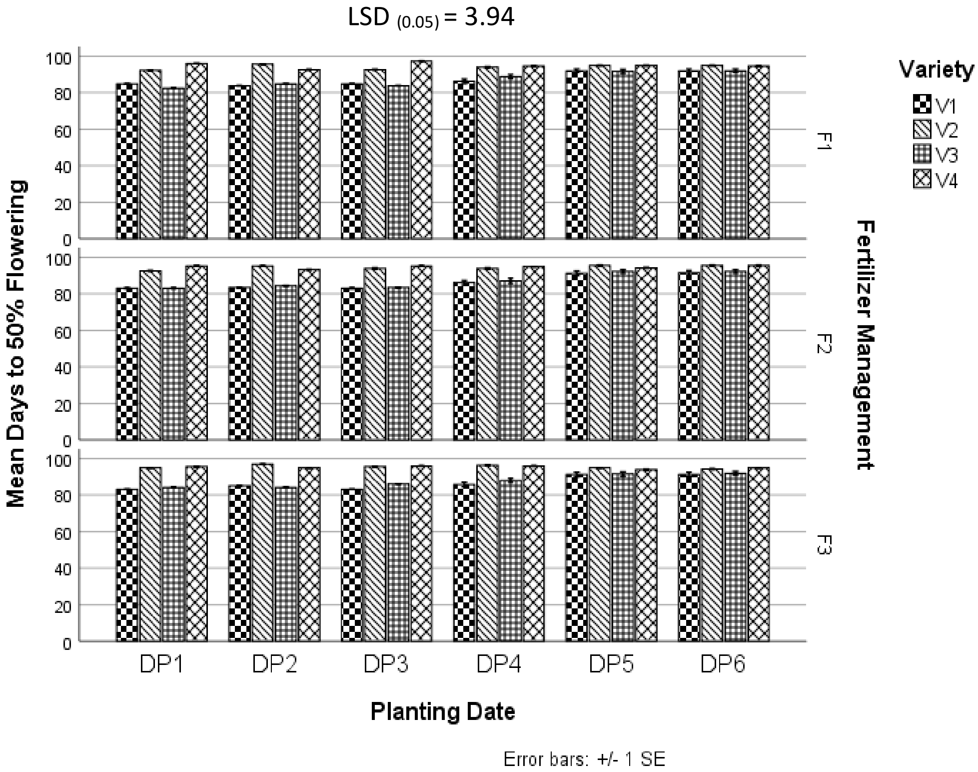

Figure 20: Effect of planting date, variety and split nitrogen fertilizer management regime on days to fifty percent flowering of rice grown in the Northern Savannah Agro ecological zone of Ghana. Bars represent the SEM.DP1 = First planting, DP2 = Second planting, DP3 = Third planting, DP4 = Fourth planting, DP5 = Fifth planting, DP6 = Sixth planting, F1 = Fertilizer management 1, F2 = Fertilizer management 2, F3 = Fertilizer management 3, V1 = Agra, V2 = Gbewaa, V3 = Exbaika, V4 = Perfume Irrigated.

4.1.4 Impact of production inputs and timing on number of days to physiological maturity

There was no three-way interaction between variety, split nitrogen application regime and date of planting on number days to physiological maturity (Table 1). However, number of days to maturity was significantly ($p < 0.05$) influenced by the interaction of variety and fertilizer management and variety as a sole factor (Table 1).

With the interaction of variety and fertilizer management, Exbaika with N applied at rate of ½ at early tillering + ½ at panicle differentiation (F1) recorded the least number of days to physiological maturity (Figure 4). It was followed by Agra + N applied at rates of ½ at early tillering + ½ at panicle differentiation (F1), which was similar to Agar + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) and Exbaika + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3). Gbewaa + N applied at rates of ½ at early tillering + ½ at panicle differentiation (F1) recorded the highest number of days to physiological maturity, followed by Perfume Irrigated + N applied at rates of ½ at early tillering + ½ at panicle differentiation (F1), at par with Gbewaa + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) and Perfume Irrigated + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3) (Figure 4).

LSD $_{(0.05)}$ =5.3

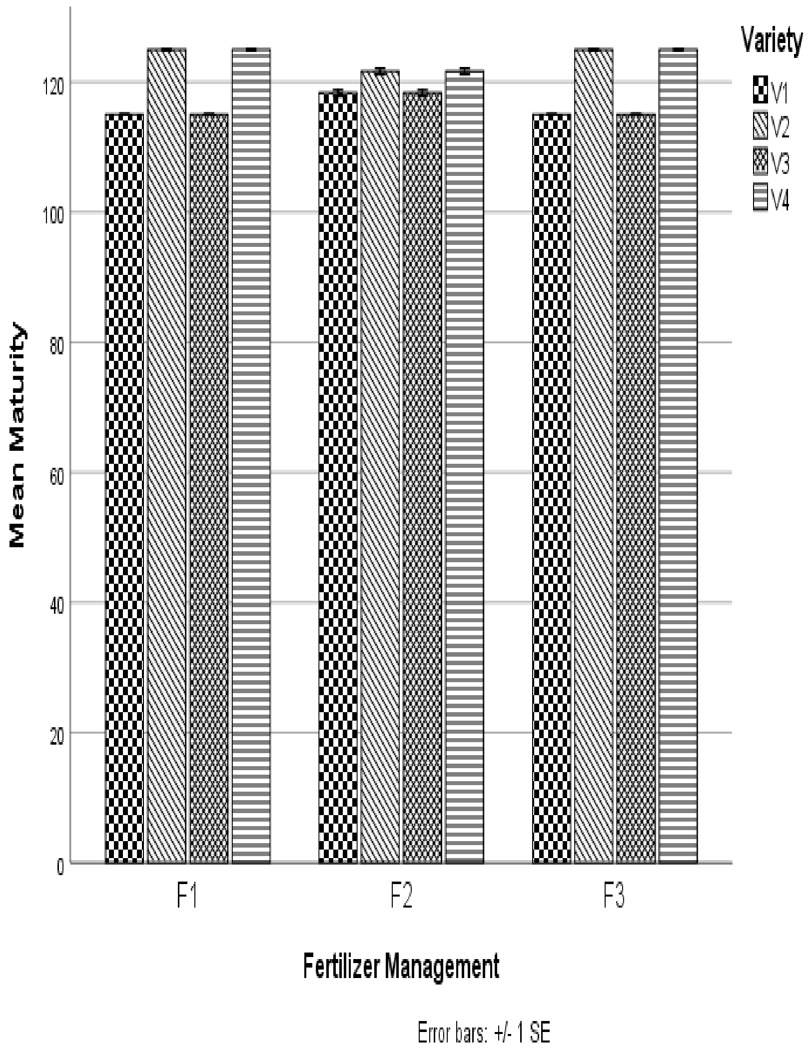

Figure 21: Effect of split nitrogen fertilizer management regime and variety on number of days to physiological maturity of perfumed rice grown in the Northern Savanna Agro ecological zone of Ghana. Bars represent the SEM. F1 = Fertilizer management 1, F2 = Fertilizer management 2, F3 = Fertilizer management 3, V1 = Agra, V2 = Gbewaa, V3 = Exbaika, V4 = Perfume Irrigated

4.1.5 Impact of production inputs and timing on yield of rice

Paddy yield was significantly ($p < 0.05$) influenced by the interaction of harvest cycle and planting date but not by the four-way interaction of all factors (Table 1).

With the interaction of planting date and harvest cycle, Second Planting + Harvest Cycle 3 recorded the highest yield, followed by Second Planting + Harvest Cycle 2, Third Planting + Harvest Cycle 3 which was at par with Second Planting + Harvest Cycle 4, First Planting + Harvest Cycle 4 and Sixth Planting + Harvest Cycle 3 (Figure 5). The lowest paddy yield was recorded by Sixth Planting + Harvest Cycle 6. It was followed by Fifth Planting + Harvest Cycle 6 and Sixth Planting + Harvest Cycle 5 respectively (Figure 5).

Planting date and harvest cycle as sole factors also had significant ($p < 0.05$) effect on paddy yield. With regards to the sole application of planting date, Second Planting recorded the highest yield, followed by First Planting. The least yield was recorded by Sixth Planting which was followed by Fifth Planting.

For the sole application of harvest cycle on yield, the lowest yield was recorded by Harvest Cycle 6 at par with Harvest Cycle 5. The highest paddy yield was recorded by Harvest Cycle 3, followed by Harvest Cycle 2.

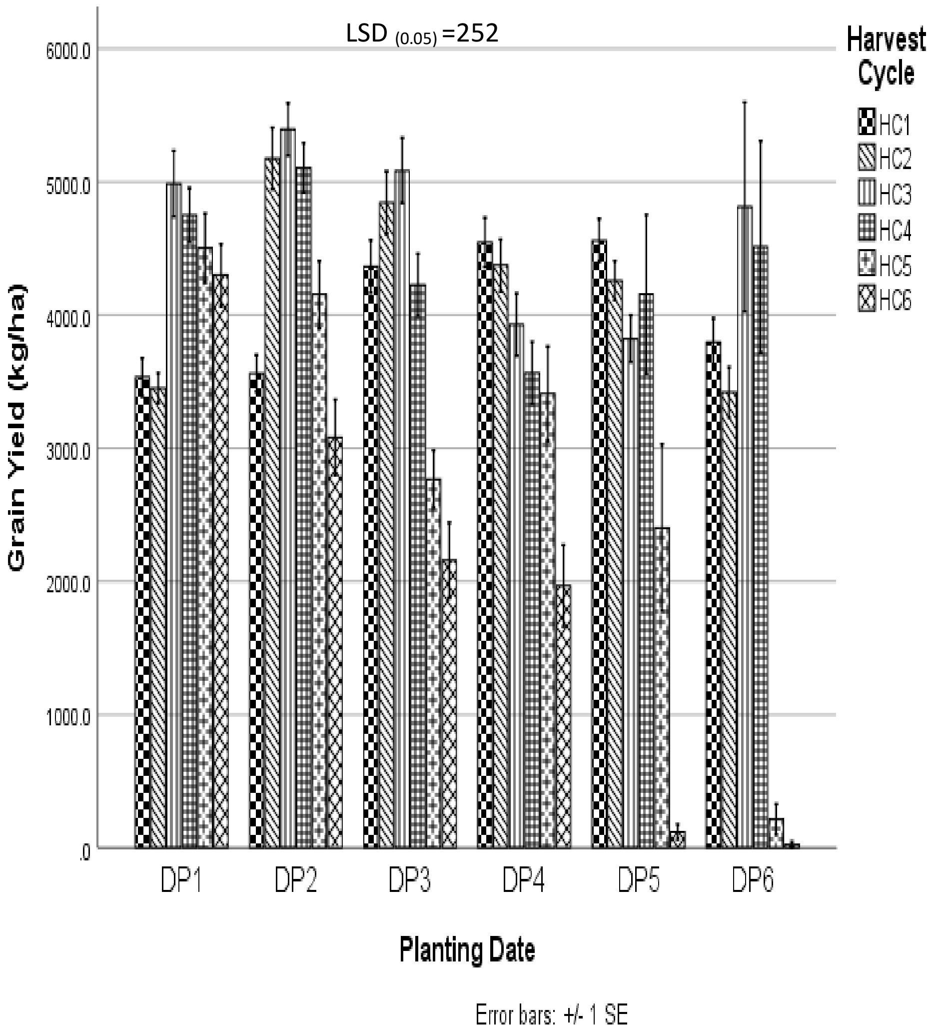

Figure 22: Effect of planting date and harvest cycle on paddy yield in the Northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

4.1.6 Impact of production inputs and timing on percentage (%) grain moisture content

Whilst there was no significant four or three-way interaction effect of variety, planting date, split nitrogen fertilizer management regime and harvest cycle on grain moisture content at harvest, there was a significant two-way interaction effect of variety and harvest cycle ($p < 0.01$), and also planting date and harvest cycle ($p < 0.001$) on grain moisture at harvest (Table 1). With the interaction of harvest cycle and planting date, Fourth Planting + Harvest Cycle 1 recorded the highest moisture content (Figure 6). It was followed by Sixth Planting + Harvest Cycle 1. The lowest moisture content at harvest was recorded by Sixth Planting + Harvest Cycle 6. It was followed by Fifth Planting + Harvest Cycle 6 and Sixth Planting + Harvest Cycle 5 respectively.

With the interaction of variety and harvest cycle, Exbaika + Harvest Cycle 1 recorded the highest grain moisture at harvest. It was followed by Agra + Harvest Cycle 1 and Gbewaa + Harvest Cycle 1 respectively. Perfumed irrigated + Harvest Cycle 6 recorded the lowest grain moisture at harvest. It was followed by Gbewaa + Harvest Cycle 6, Exbaika + Harvest Cycle 6 and Agra + Harvest Cycle 6 respectively (Figure 7).

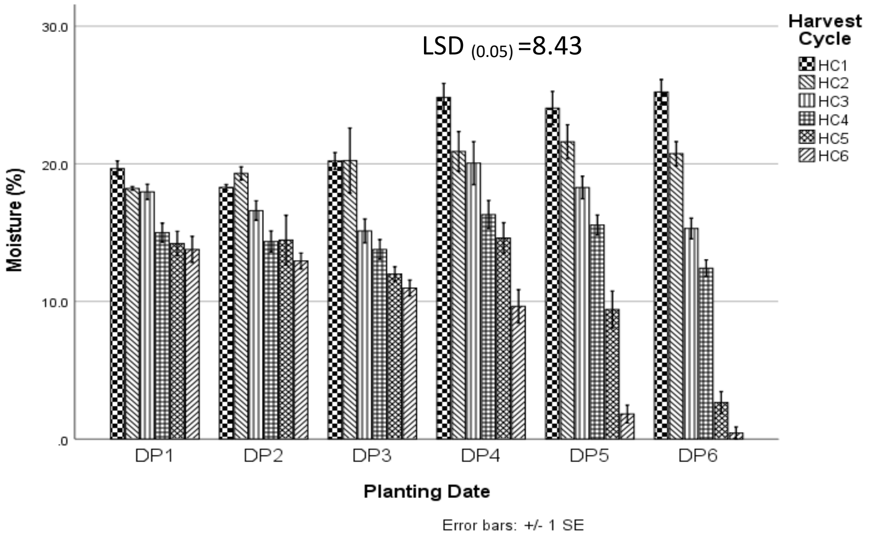

Figure 23: Effect of planting date and harvest cycle on grain moisture at harvest of rice grown in the Northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

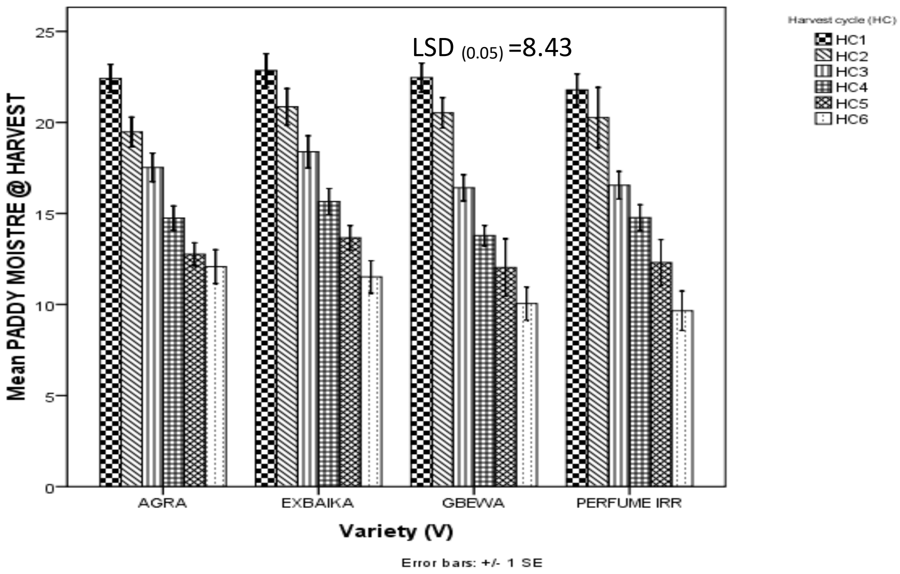

Figure 24: **Effect of variety and harvest cycle on paddy grain moisture at harvest in the Northern Savanna Agro ecological zone of Ghana. Bars represent SEM**

4.1.7 Correlation between paddy yield and paddy growth parameters in the Northern Savannah Agro ecological zone of Ghana

The correlation analysis for growth and yield parameters indicated a strong positive relationship between number of panicles per stand and the number of tillers per stand ($R^2 = 0.9195$; $p < 0.001$) (Table 2). Another strong positive relationship was observed between number of days to 50% flowering and number of days to maturity ($R^2 = 0.5250$; $p < 0.001$). However, grain yield was observed to have weak positive relationship with number of panicles per stand ($R^2 = 0.1189$; $p < 0.05$), and number of tillers per stand ($R^2 = 0.1358$; $p < 0.05$).

Also, grain moisture was observed to have weak but negative relationships with number of panicles per stand ($R^2 = -0.0746$; $p < 0.01$), number of tillers per stand ($R^2 = -0.0812$; $p < 0.01$) and number of days to 50% flowering ($R^2 = -0.1330$; $p < 0.05$).

Table 2: Pearson's correlation matrix for growth and yield parameters of rice grown in the Northern Savannah Agro ecological zone of Ghana

	PPS	DFF	DM	GY	GM
TPS	0.9195*	0.0460	0.0305	0.1358*	-0.0812**
PPS		0.0130	-0.0107	0.1189*	-0.0746**
DFF			0.5250*	-0.0041	-0.1330*
DM				-0.0242	-0.0389
GY					0.1577*

*DFF = Days to 50 % flowering, DM = Days to Maturity, TPS = Tiller per stand, PPS = Panicle per stand, GM = Grain Moisture, GY = Grain yield; ** = Significant at p < 0.01, * = Significant at p < 0.05*

4.1.8 Linear regressions and model fit parameters for statistically correlated ($P < 0.05$) growth and paddy yield parameters in the Northern Savannah Agro ecological zone of Ghana

The regression equations for all the significant relationships observed in Table 2 are shown in Table 3. The R^2 value for the relationship between days to maturity and days to 50 % flowering (0.275) indicates that 27.5% of the changes in number of days to maturity can be explained by the changes in number of days to 50% flowering. Furthermore, the R^2value for the relationship between number of panicles per stand and number of tillers per stand was 0.845 which indicates that 84.5% of the changes in number of panicles per stand can be explained by the changes in number of tillers per stand. Impact of other growth and yield parameters on one another, remained relatively low. Grain moisture had R^2 values of 0.017, 0.005 and 0.006 with its relationship with number of days to 50% flowering, number of panicles per stand and number of tillers per stand respectively. This shows that only 1.7 %, 0.5 % and 0.6 % of the changes in grain moisture can be explained by the changes in number of days to 50% flowering, number of panicles per stand and number of tillers per stand, respectively. Also, grain yield had R^2 values of 0.024, 0.018 and 0.013 with its relationship with grain moisture, number of tillers per stand and number of panicles per stand respectively. This shows that 2.4 %, 1.8 % and 1.3 % of the changes in grain yield can be explained by the changes in grain moisture, number of tillers per stand and number of panicles per stand, respectively.

Table 3: Linear regressions and model fit parameters for statistically correlated (*P < 0.05*) growth parameters and paddy yield in the Northern Savannah Agro ecological zone of Ghana.

Relation	R^2	SEE	Significance level
DM = 0.4883(DFF) + 75.59	0.275	4.26	< 0.001
PPS = 0.75210(TPS) + 2.388	0.845	0.547	< 0.001
GY = 38.82(GM) + 3451	0.024	1987	< 0.001
GY = 160.7(TPS) + 2002	0.018	1994	< 0.001
GY = 172.1(PPS) + 1991	0.013	1998	< 0.001

DFF = Days to 50 % flowering, DM = Days to Maturity, TPS = Tiller per stand, PPS = Panicle per stand, GM = Grain Moisture, GY = Grain yield, SEE= standard error of the estimate, R^2 = coefficient of determination.

4.2 Impact of production inputs and timing on percentage paddy crackness

Table 4 shows the sole and interactive effect of planting date, rice variety, split nitrogen fertilizer management regime, time of harvesting and duration of storage on paddy crackness.

Table 4: Factorial significance (*p<0.05*) of planting date (PD), rice variety (VA), split nitrogen fertilizer management regime (FM), and harvest cycle (HC) on paddy crackness at harvest and at different storage durations in the northern ıa Agro ecological zone of Ghana.

	General	At harvest	Week		Month					
			One	Two	One	Two	Three	Four	Five	Six
	**	**	**	**	**	**	**	**	**	**
	**	*	*	**	**	**	ns	ns	ns	ns
	**	**	**	**	**	**	**	**	**	**
	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
VA	**	ns	ns	ns	ns	ns	ns	ns	ns	ns
HC	**	**	**	**	**	**	**	*	**	**
HC	**	ns	ns	ns	*	ns	*	ns	ns	ns
* FM	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
FM	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
FM	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
VA * HC	*	ns	ns	**	**	ns	**	ns	ns	ns
VA * FM	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
HC * FM	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
HC * FM	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
VA * HC* FM	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

*0.01, *P < 0.05, ^{ns} P > 0.05, PD=Planting date, VA=Variety, FM=Fertilizer management, HC=Harvest cycle. For ne period (vertical column), factorial combinations were analyzed following the order: quaternary, tertiary, and interactions, before sole factor significance. Data that showed significant interactions and/or sole factor effect (shaded yellow) were used for computing graphs and for posthoc analyses.*

The table also shows how paddy crackness is affected by a combination of these factors at time of harvest, some weeks after harvest up to six (6) months of storage.

4.2.1 Impact of production inputs and harvest timing on percentage (%) mean paddy crackness

Generally, mean paddy crackness was significantly affected ($p < 0.05$) by the interaction of variety, planting date and harvest cycle. Harvest cycle 6, Third Planting and Agra rice variety recorded the highest crackness percentage of 78%, whilst, harvest cycle 6, Sixth Planting and Agra rice variety recorded the least cracking percentage of 24% (Figure 8). Apart from Sixth Planting and Harvest cycle 6, cracking in paddy generally increased with delayed planting and delayed harvesting.

In contrast, early planting and early harvesting reduced grain cracking. Perfumed irrigated variety, planted at Fourth Planting and for all harvesting cycles consistently had lower percentage cracking except for Harvest cycle six (6).

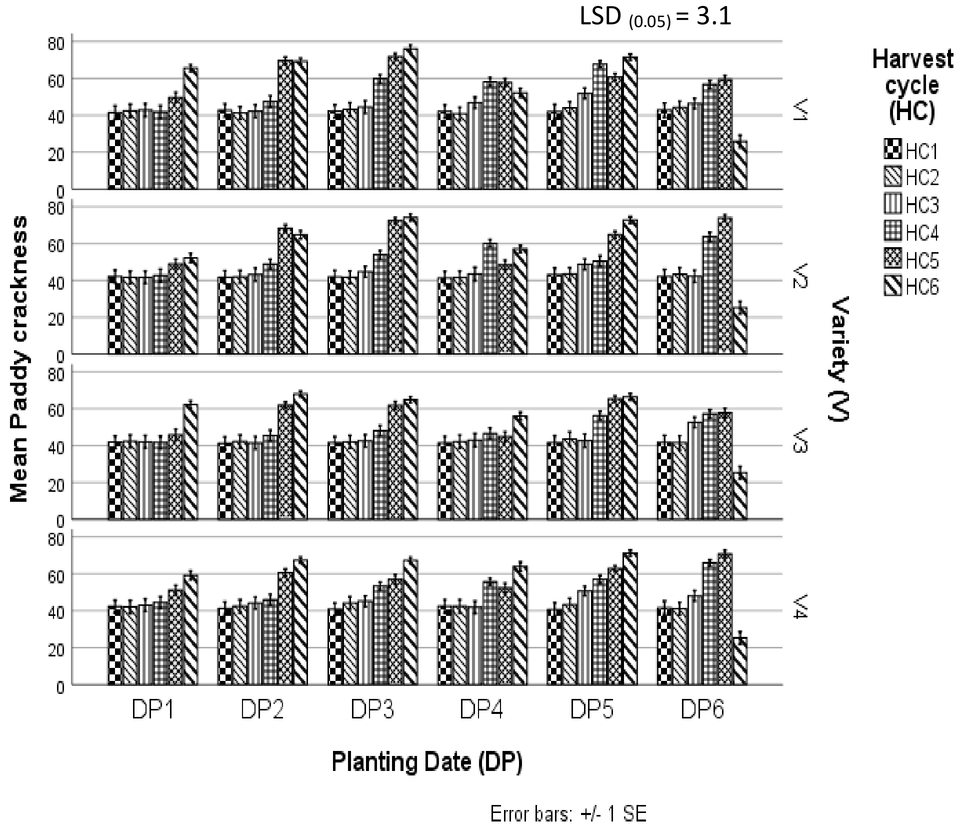

Figure 25: Effect of planting date, harvest cycle and variety on mean paddy cracking in the Northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.DP1 = First planting, DP2 = Second planting, DP3 = Third planting, DP4 = Fourth planting, DP5 = Fifth planting, DP6 = Sixth planting, V1 = Agra, V2 = Gbewaa, V3 = Exbaika, V4 = Perfume Irrigated, HC1= First harvest, HC2 = Second harvest, HC3 = Third harvest, HC4 = Fourth harvest, HC5 = Fifth harvest, HC6 = Sixth harvest. V1 = Agra, V2 = Gbewaa, V3 = Exbaika, V4 = Perfume Irrigated.

4.2.2 Impact of production inputs and timing on percentage (%) paddy cracking at harvest

Paddy cracking at harvest was significantly affected (*$p < 0.05$*) by the interaction of planting date and harvesting cycle (Table 4).

With the interaction of planting date and harvest cycle, Second Planting + Harvest Cycle 5 recorded highest percentage paddy crackness at harvest. It was followed by Second Planting + Harvest Cycle 6, which was at par with Fifth Planting + Harvest Cycle 6. The least percentage paddy crackness at harvest was recorded by First planting + Harvest Cycle 2. It was followed by First Planting + Harvest Cycle 1, Second Planting + Harvest Cycle 1, Third Planting + Harvest Cycle 1 and Fifth Planting + Harvest Cycle 1 respectively (Figure 9a). Harvest Cycle 5 + Second Planting recorded the highest crackness percentage of 71%, whilst Harvest Cycle 1 and 2, with First and Second Planting consistently had the least cracking percentage of 29-31% (Figure 9a): a percentage crack reduction of about 130-145%. Early planting and early harvesting tended to reduce paddy cracking. In contrast, late planting and late harvesting tended to result in high paddy cracking at harvest.

The sole application of variety also had significant (*$p < 0.05$*) influence on paddy crackness at harvest (Table 4). The Agra variety had the highest paddy crackness at harvest. It was followed by Gbewaa which was at par with Perfume Irrigated. The Exbaika variety recorded the lowest paddy crackness at harvest (Figure 9b).

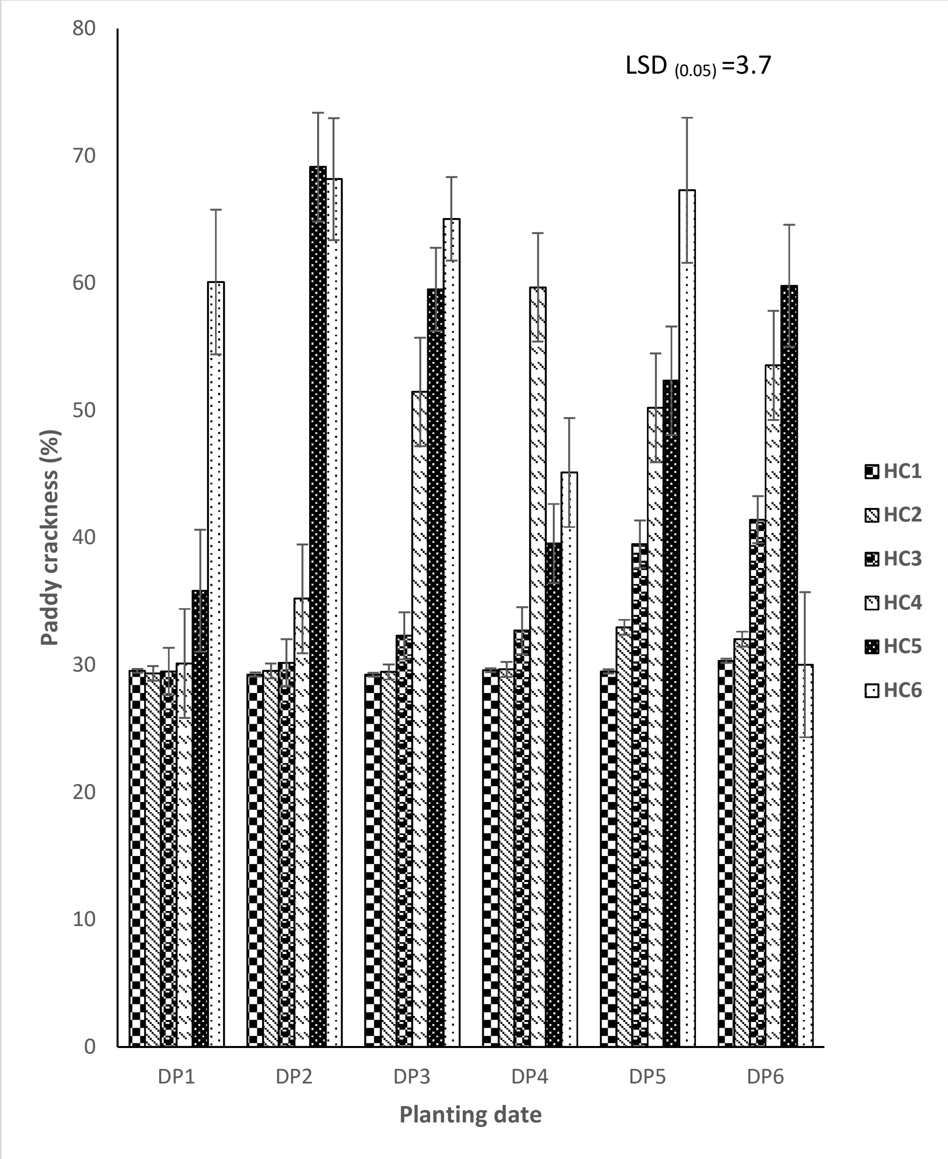

Figure 26a: Effect of planting date and harvest cycle on paddy crackness at harvest under rainfed production systems in the Northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

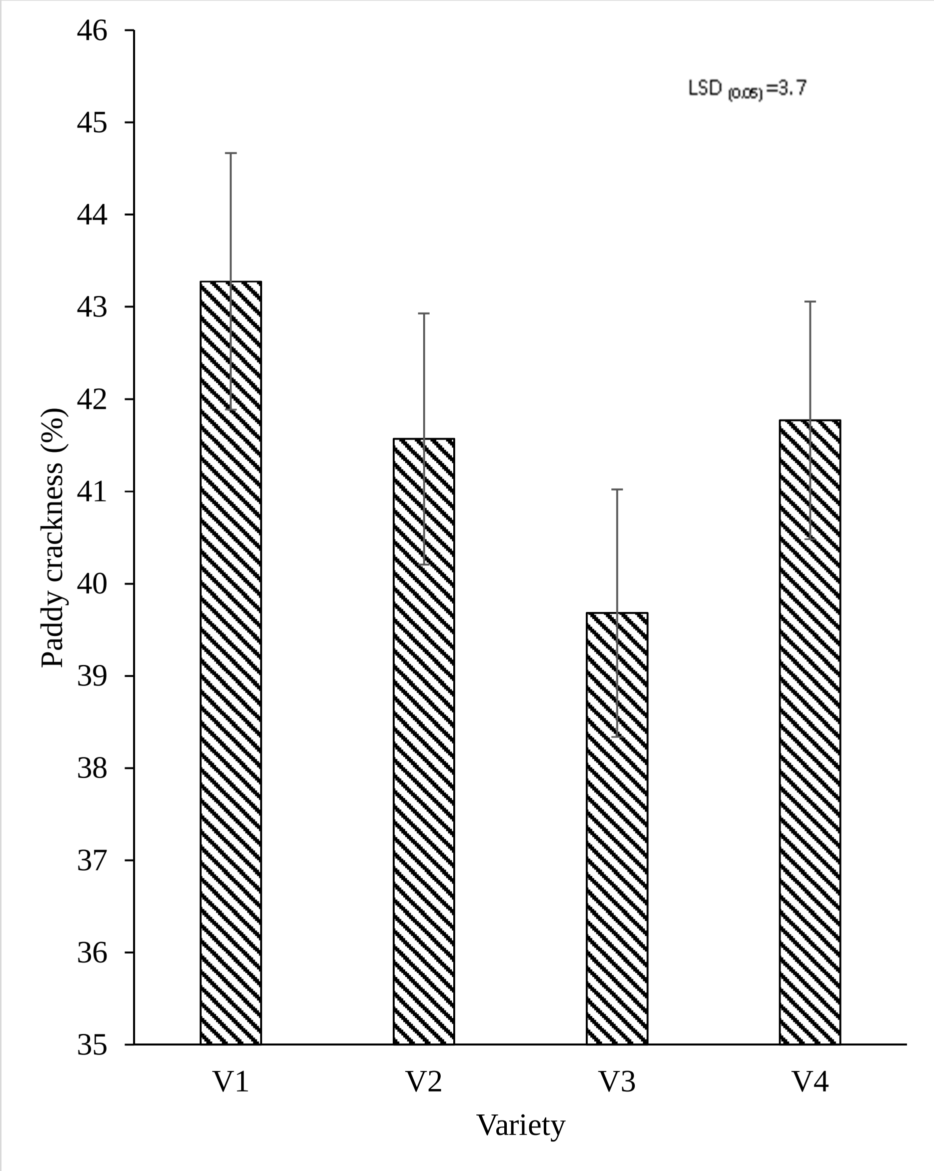

Figure 9b: Effect of perfumed rice varieties on paddy crackness at harvest under rain-fed production systems in the Northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

4.2.3 Impact of production inputs and timing on percentage (%) paddy cracking at one week of storage

Paddy cracking at 1 week of storage was significantly affected (*$p < 0.05$*) by the interaction of planting date and harvest cycle as well as the sole application of the two factors (Table 4). Planting date 2 and harvest cycle 5 recorded the highest crackness percentage of 72%, whilst harvest cycle 2 and planting date 1 had the least cracking percentage of 29% (Figure 10a). Treatments with the highest crackness were followed by Second Planting + Harvest Cycle 6, Fifth Planting + Harvest Cycle 6, Third Planting + Harvest Cycle 6 and Sixth Planting + Harvest Cycle 5 respectively. The lowest was recorded by Sixth Planting + Harvest Cycle 6, followed by First Planting + Harvest Cycle 1, Second Planting + Harvest Cycle 1 and Third Planting + Harvest Cycle 1 respectively (Figure10a). At all planting dates, Harvest Cycle 1 and Harvest Cycle 2 consistently had lower and comparable cracks.

The sole application of variety also had significant ($p < 0.05$) influence on paddy crackness at harvest (Table 4). With this, the Agra variety had the highest paddy crackness at harvest. It was followed by Gbewaa which was at par with Perfume Irrigated. Exbaika recorded the lowest paddy crackness at harvest (Figure 10b).

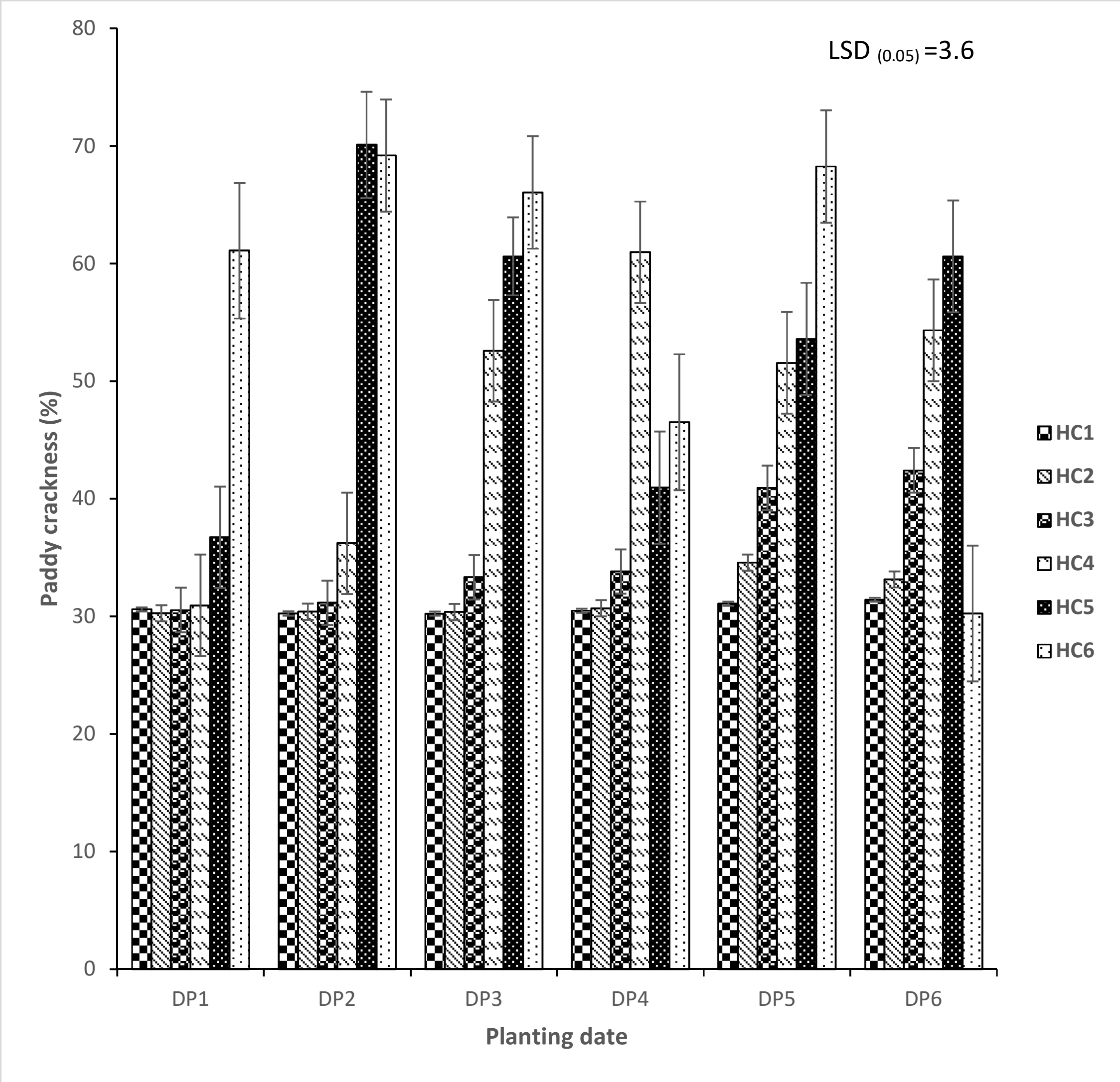

Figure 27a: Effect of Planting date and harvest cycle on paddy crackness at one week of storage in the Northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

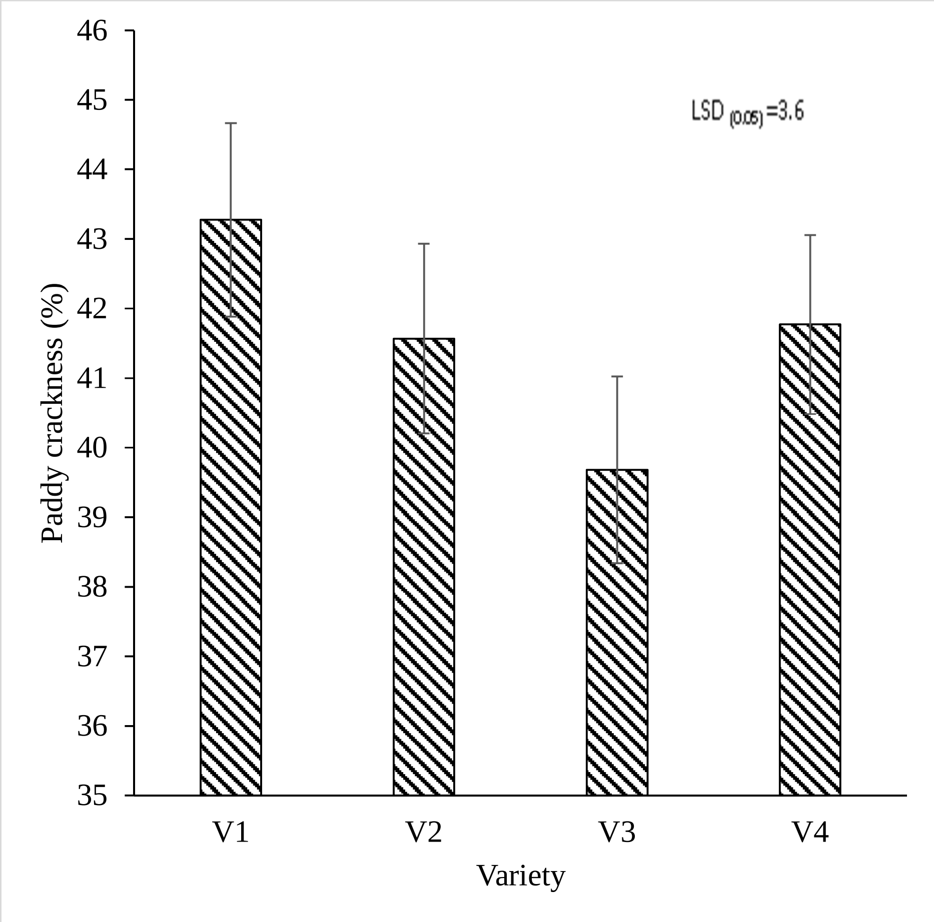

Figure 10b: Effect of perfumed rice varieties on paddy crackness at one week of storage under rain-fed production systems in the Northern ecological zone of Ghana. Bars represent the SEM.

4.2.4 Impact of production inputs and timing on percentage (%) paddy cracking at two weeks of storage

Paddy crackness at 2 weeks of storage was significantly affected ($p < 0.05$) by the interaction of planting date, variety and harvesting cycle (Table 4). With this interaction, Agra + Second Planting + Harvest Cycle 5 recorded the highest paddy crackness at two weeks of storage (Figure 11). It was followed by Agra + Third Planting + Harvest Cycle 6, Gbewaa + Third Planting + Harvest Cycle 6 and was at par with Gbewaa + Sixth Planting + Harvest Cycle 5.

The lowest was recorded by Perfume Irrigated + Third Planting + Harvest Cycle 1. It was followed by Perfume Irrigated + First Planting + Harvest Cycle 1, which was similar to Gbewaa + First Planting + Harvest Cycle 1, Exbaika + First Planting + Harvest Cycle 1, Agra + First Planting + Harvest Cycle 1 and Gbewaa + Second Planting + Harvest Cycle 1.

LSD (0.05) =3.9

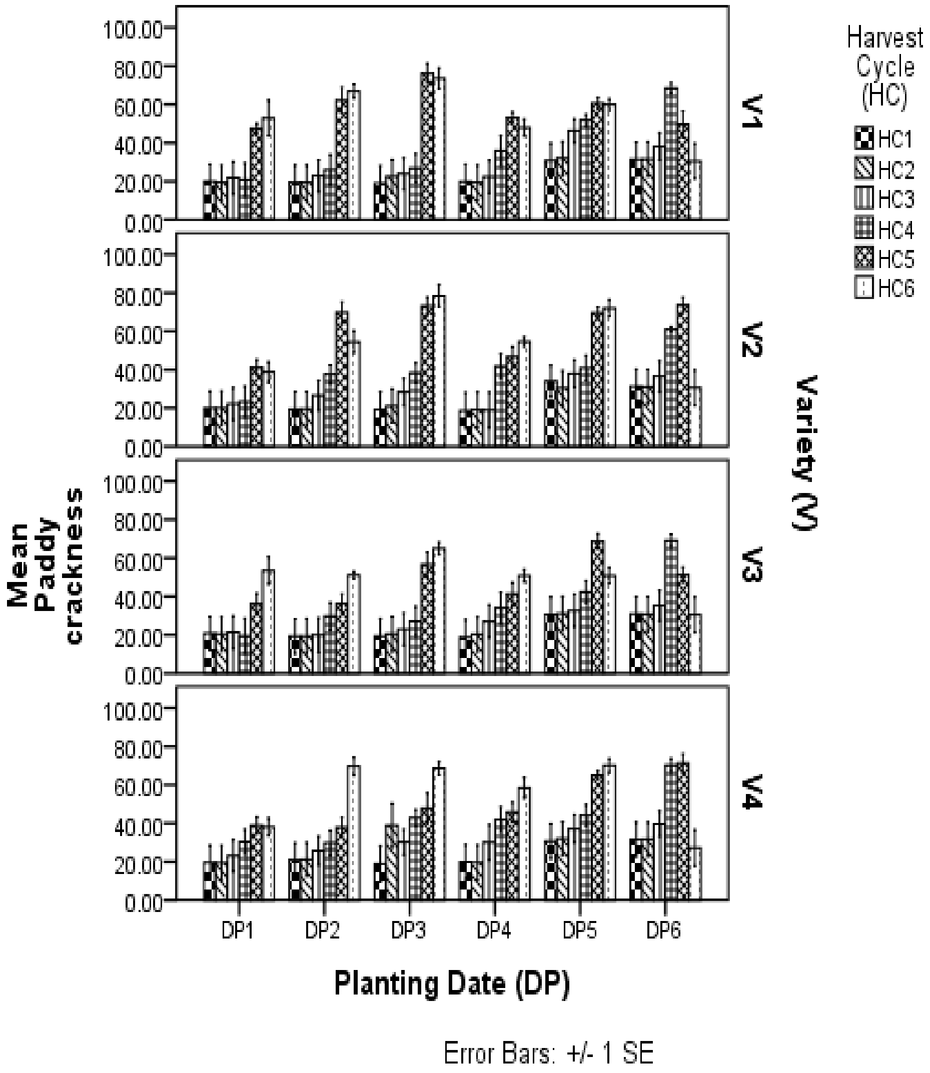

Figure 28: Effect of Planting date, variety and harvest cycle on paddy crackness at two weeks of storage in the Northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

4.2.5 Impact of production inputs and timing on percentage (%) paddy cracking at one month of storage

Paddy crackness at one month of storage was significantly affected (*$p < 0.05$*) by the interaction of planting date, variety and harvest cycle (Table 4). Agra + Third Planting + Harvest Cycle 5 recorded the highest paddy crackness at one month of storage (Figure 12). It was followed by Gbewaa + Third Planting + Harvest Cycle 6, which was at par with Agra + Third Planting + Harvest Cycle 6, Gbewaa + Sixth Planting + Harvest Cycle 5 and Perfume Irrigated + Second Planting + Harvest Cycle 6.

The lowest paddy crackness at one month of storage was recorded by Gbewaa + Fifth Planting + Harvest Cycle 2. It was followed by Exbaika + First Planting + Harvest Cycle 4, Exbaika + Second Planting + Harvest Cycle 2 and Perfume Irrigated + First Planting + Harvest Cycle 1 respectively.

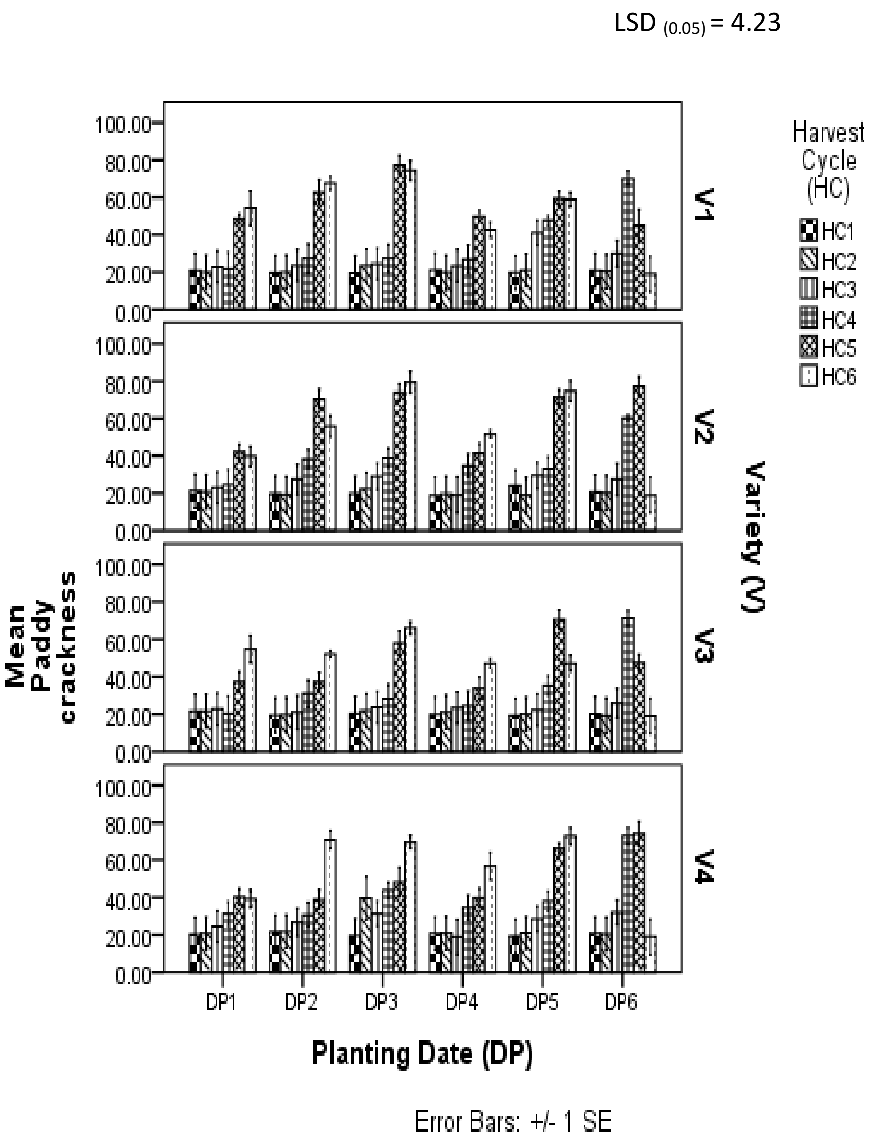

Figure 29: Effect of planting date, variety and harvest cycle on paddy crackness at one month of storage in the Northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

4.2.6 Impact of production inputs and timing on percentage (%) paddy cracking at two months of storage

Paddy crackness at 2 months of storage was significantly affected ($p < 0.05$) by the interaction of planting date and harvesting cycle and was also affected by variety as sole factor (Table 4).

For interaction of planting date and harvest cycle, Third Planting + Harvest Cycle 6 recorded the highest, followed by Fifth Planting + Harvest Cycle 5, Sixth Planting + Harvest Cycle6, Sixth Planting + Harvest Cycle 5 and Third Planting + Harvest Cycle 5 respectively (Figure 13a). The lowest paddy cracking was recorded by Sixth Planting + Harvest Cycle 1, followed by Third Planting + Harvest Cycle 2 and Second Planting + Harvest Cycle 2 which were at par. It was follow by First Planting + Harvest Cycle 1, Second Planting + Harvest Cycle 1 and Third Planting + Harvest Cycle 1 which were all similar (Figure 13a).

With regards to the significant varietal effect, Agra had the highest paddy crackness at harvest. It was followed by Gbewaa which was at par with Perfume Irrigated. Exbaika recorded the lowest paddy crackness at harvest (Figure 13b).

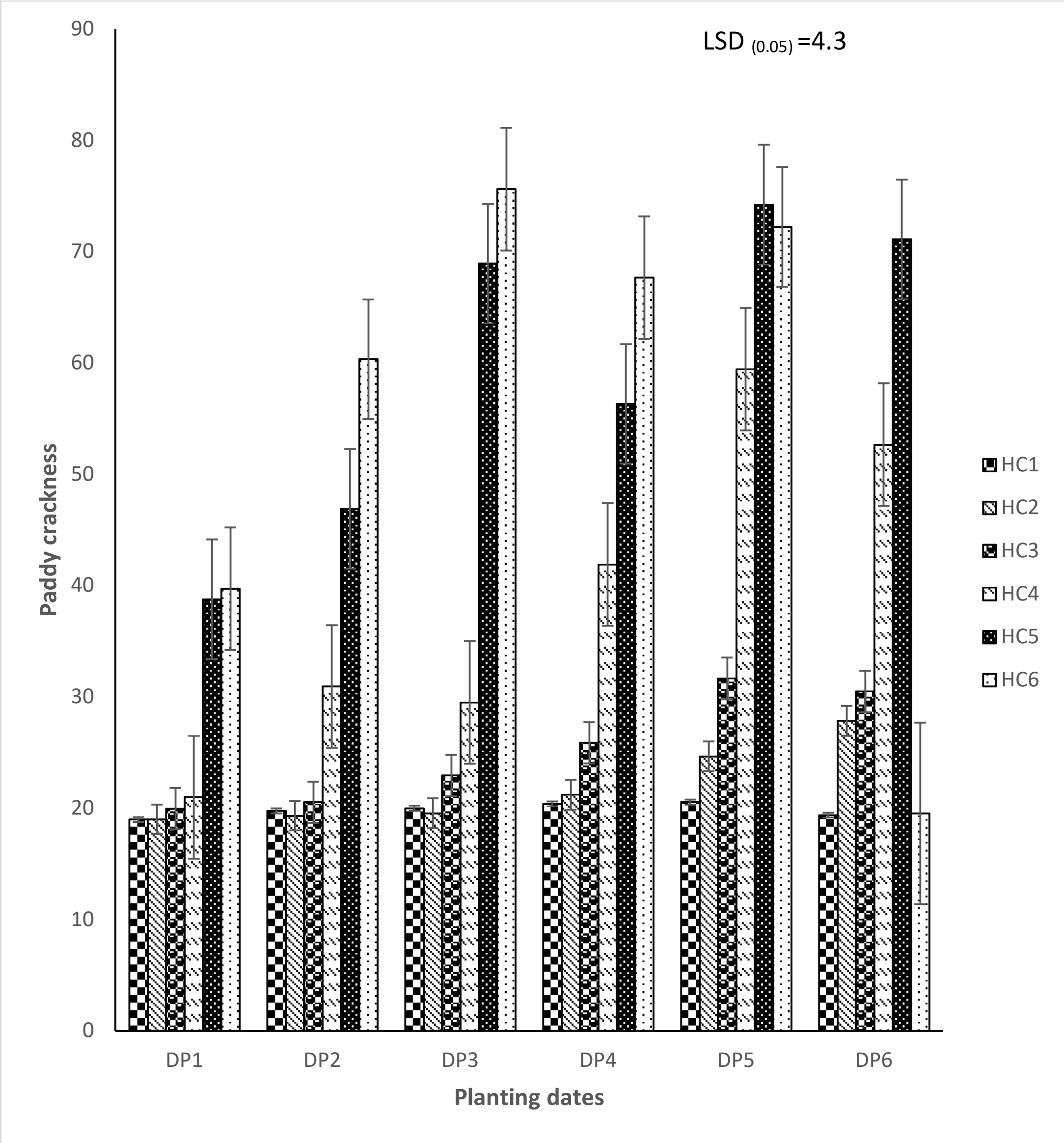

Figure 30a: Effect of Planting date and harvest cycle on paddy crackness at two months of storage in the northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

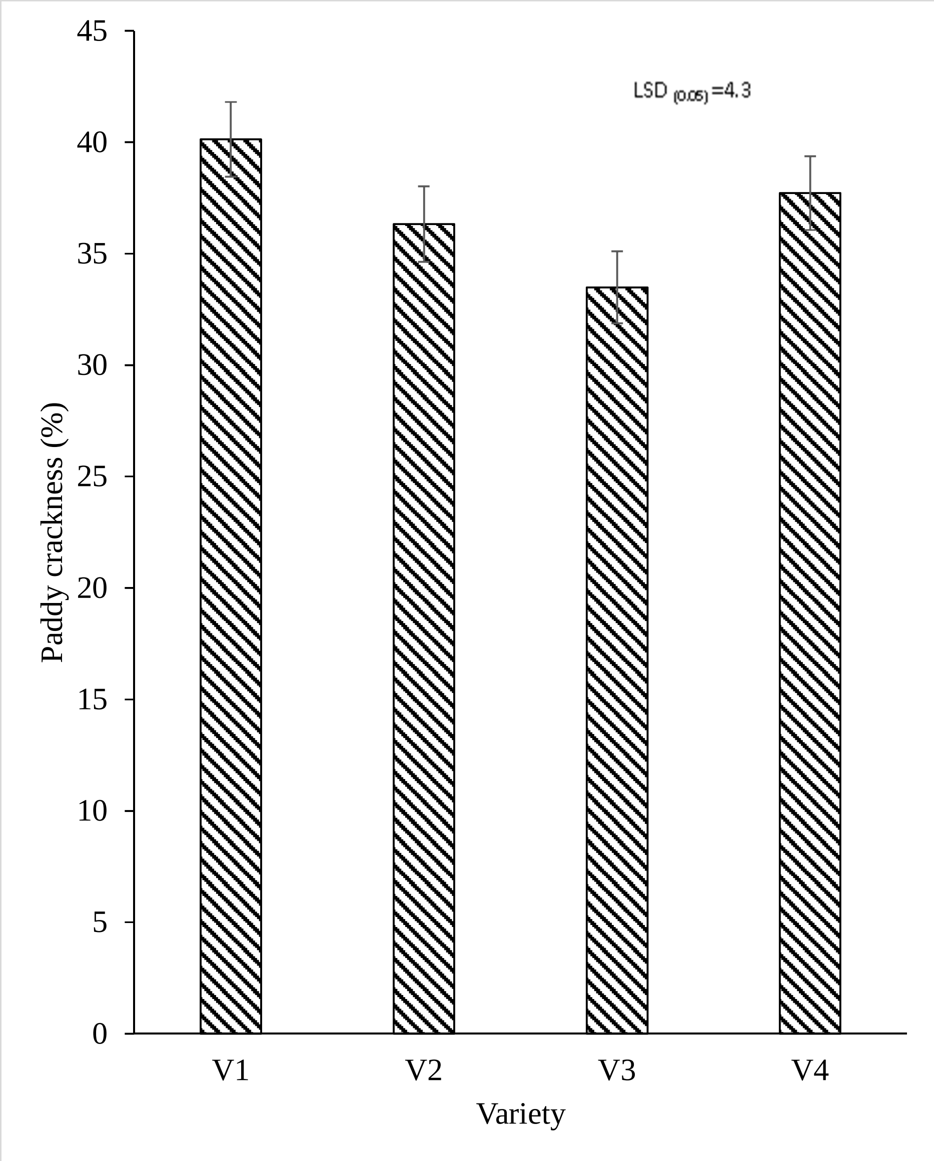

Figure 13b: Effect of perfumed rice varieties on paddy crackness at two months of storage in the Northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

4.2.7 Impact of production inputs and timing on percentage (%) paddy cracking at three months of storage

Paddy crackness at three months of storage was significantly affected (*$p < 0.05$*) by the interaction of planting date, variety and harvesting cycle (Table 4). Agra + Third Planting + Harvest Cycle 6 recorded the highest paddy crackness at three months of storage. It was followed by Gbewaa + Third Planting + Harvest Cycle 6, and was at par with Agra + Fifth Planting + Harvest Cycle 1, Exbaika + Fifth Planting + Harvest Cycle 2 and Exbaika + Fifth Planting + Harvest Cycle 2 (Figure 14).

The lowest paddy crackness was recorded by Perfume Irrigated + Sixth Planting + Harvest Cycle 6. It was followed by Gbewaa +Sixth Planting + Harvest Cycle 6 and was similar with Exbaika + Sixth Planting + Harvest Cycle 6 and Agra + Sixth Planting + Harvest Cycle 6.

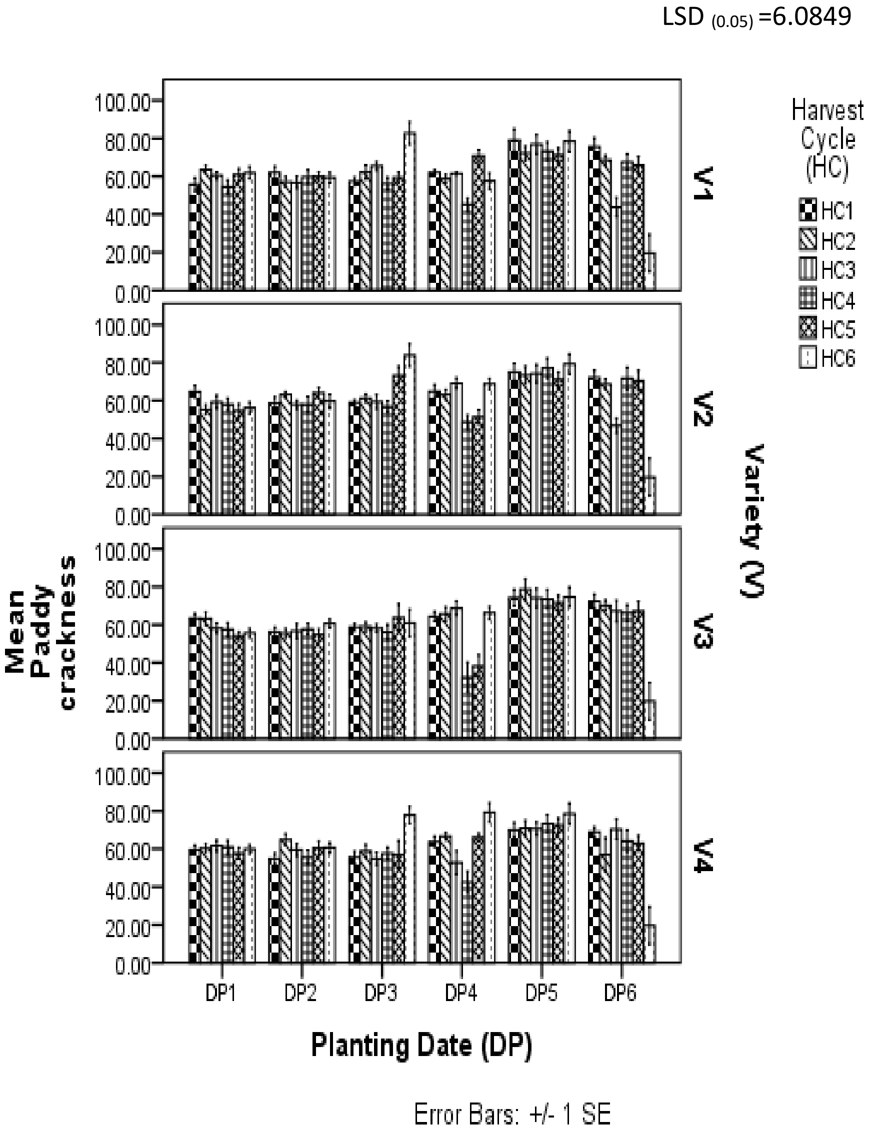

Figure 31: Effect of planting date, variety and harvest cycle on paddy crackness at three months of storagein the northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

4.2.8 Impact of production inputs and timing on percentage (%) paddy cracking at four months of storage

Paddy crackness at 4 months of storage was significantly affected ($p < 0.05$) by the interaction of planting date and harvesting cycle (Table 4). Sixth Planting + Harvest Cycle 5 had the highest paddy crackness (Figure 15). It was followed by Third Planting + Harvest Cycle 4, Fourth Planting + Harvest Cycle 3, Sixth Planting + Harvest Cycle 3, Sixth Planting + Harvest Cycle 3, Fourth Planting + Harvest Cycle 6 and First Planting + Harvest Cycle 5, which were all at par.

The lowest was recorded by Sixth Planting + Harvest Cycle 6. It was followed by Fifth Planting + Harvest Cycle 3, Third Planting + Harvest Cycle 1, which was at par with First Planting + Harvest Cycle 1 and Fourth Planting + Harvest Cycle 2 (Figure 15).

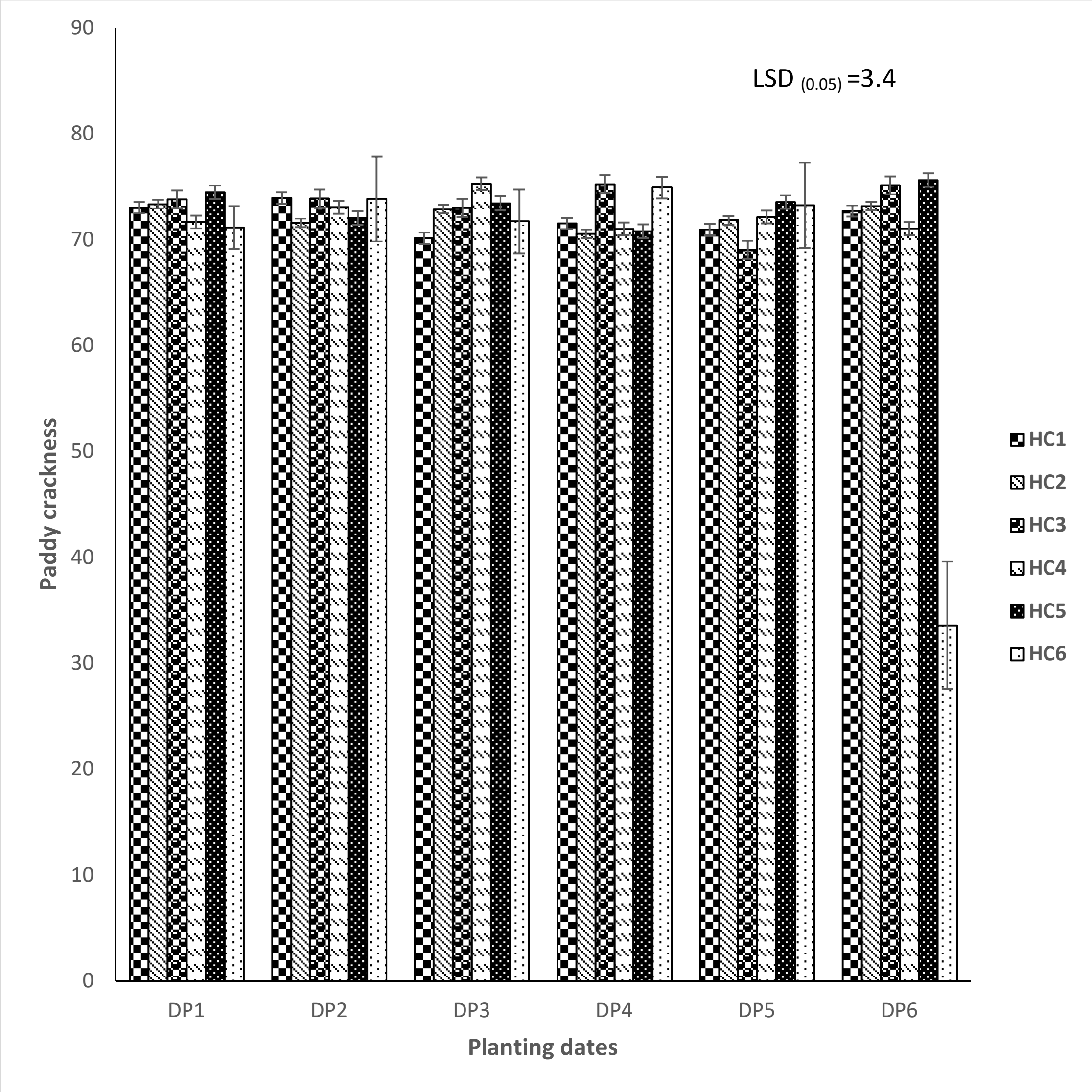

Figure 32: Effect of planting date and harvest cycle on paddy cracking at four months of storage in the northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

4.2.9 Impact of production inputs and timing on percentage (%) paddy cracking at five months of storage

Paddy crackness at 5 months of storage was significantly affected ($p < 0.05$) by the interaction of planting date and harvesting cycle (Table 4). Planting date 6 and harvest cycle 1 recorded the highest crackness percentage of 75%, whilst planting date 6 and harvest cycle 6 had the least cracking percentage of 30% (Figure. 16). The highest cracking was followed by Fourth Planting + Harvest Cycle 3, which was at par with Third Planting + Harvest Cycle 3, Third Planting + Harvest Cycle 4, Second Planting + Harvest Cycle 2, Fourth Planting + Harvest Cycle 6 and Fifth Planting + Harvest Cycle 6 (Figure 16).

The lowest paddy crackness at fifth month of storage was recorded by Sixth Planting + Harvest Cycle 6. It was followed by Second Planting + Harvest Cycle 5, Fifth Planting + Harvest Cycle 2, Sixth Planting + Harvest Cycle 2 and Second Planting + Harvest Cycle 1, which were all at par.

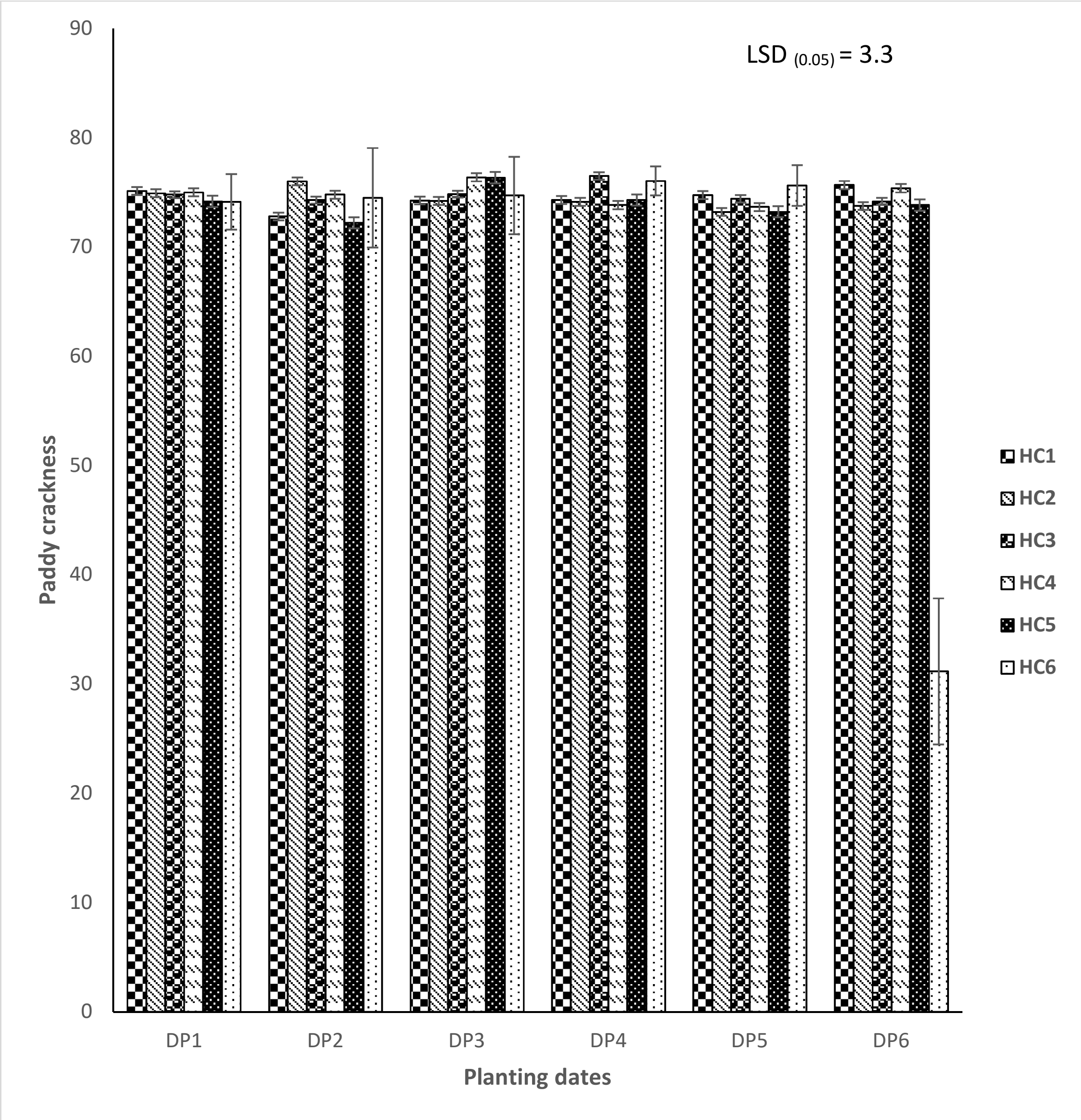

Figure 33: Effect of planting date and harvest cycle on paddy crackness at five months of storage in the northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

4.2.10 Impact of production inputs and timing on percentage (%) paddy cracking at six months of storage

Paddy crackness at 6 months of storage was significantly affected (*p <0.05)* by the interaction of planting date and harvesting cycle (Table 4). Planting date 5 and harvest cycle 6 recorded the highest crackness percentage of 74%, whilst planting date 6 and harvest cycle 6 had the least cracking percentage of 30% (Figure 17). The treatment with the highest crackness levels was followed by Second Planting + Harvest Cycle 4, Fifth Planting + Harvest Cycle 3, Third Planting + Harvest Cycle 5, Fourth Planting + Harvest Cycle 2 and First Planting + Harvest Cycle 4 respectively.

The lowest was recorded by Sixth Planting + Harvest Cycle 6. It was followed by First Planting + Harvest Cycle 3, Third Planting + Harvest Cycle 3, Sixth Planting + Harvest Cycle 2, Sixth Planting + Harvest Cycle 3and First Planting + Harvest Cycle 1 respectively (Figure 17).

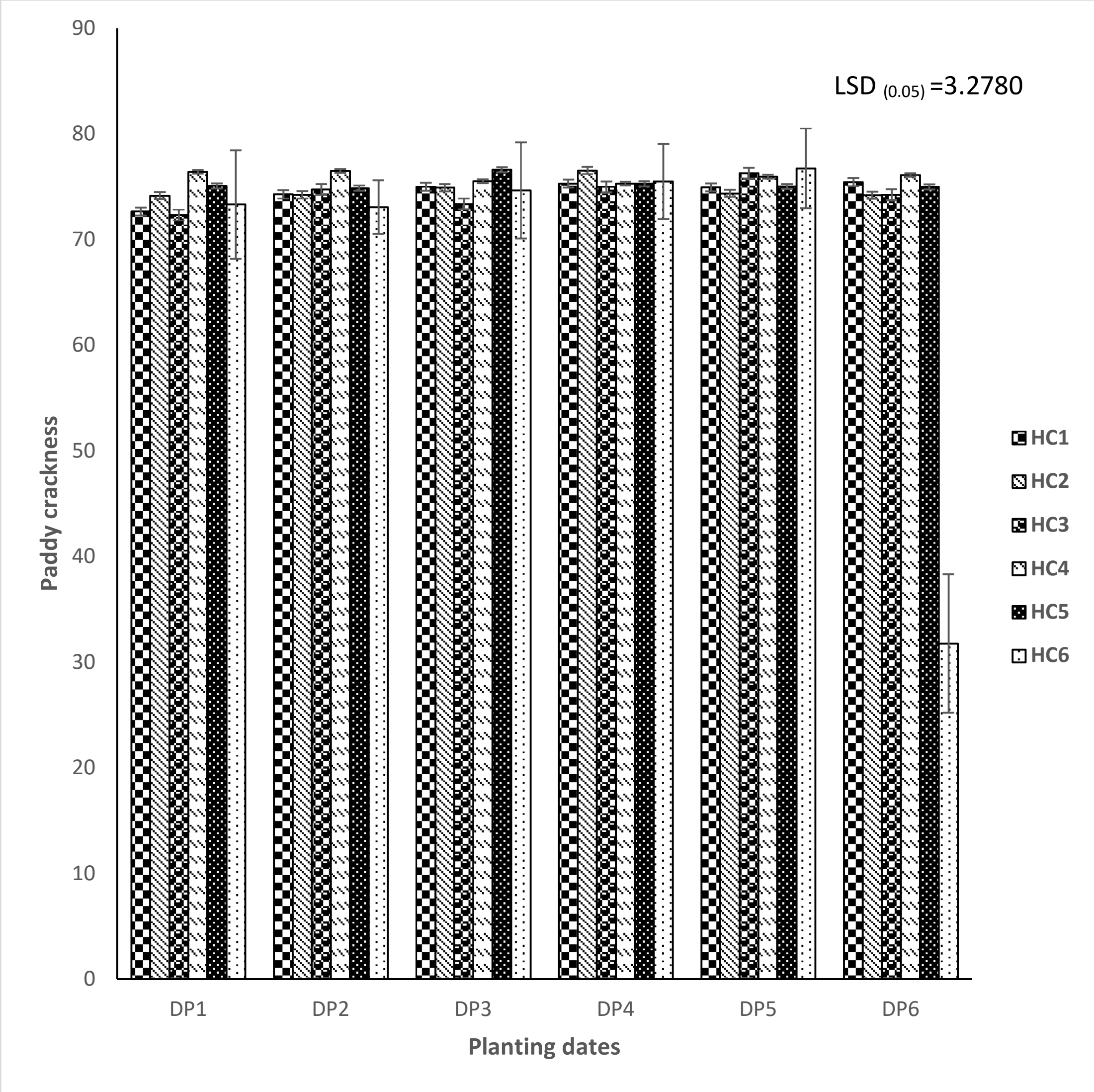

Figure 34: Effect of Planting date and Harvest cycle on paddy cracking at six months of storage in the Northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

4.2.11 Impact of planting time, harvest time and storage duration on percentage (%) paddy cracking

Paddy cracking was significantly affected (*$p < 0.05$*) by the interaction of planting date, harvesting cycle and storage duration. First Planting through to 3rd planting + First to 3rd Harvest Cycle + 1st Harvest to 2 Months Storage consistently recorded the lowest paddy cracking of 17-20% (Figure 18). The highest paddy cracking was recorded by Fourth Planting + Harvest Cycle 6 + 6 Months Storage. It was followed by Third Planting + Harvest Cycle 6 + 6 Months Storage, which was at par with Sixth Planting + Harvest Cycle 3 + 5 Months Storage, Sixth Planting + Harvest Cycle 4 + 6 Months Storage and Fifth Planting + Harvest Cycle 4 + 5 Months Storage respectively.

Early planting and early harvesting and low storage duration tended to reduce paddy cracking. In contrast, late planting, late harvesting and extended duration of storage tended to result in high paddy cracking.

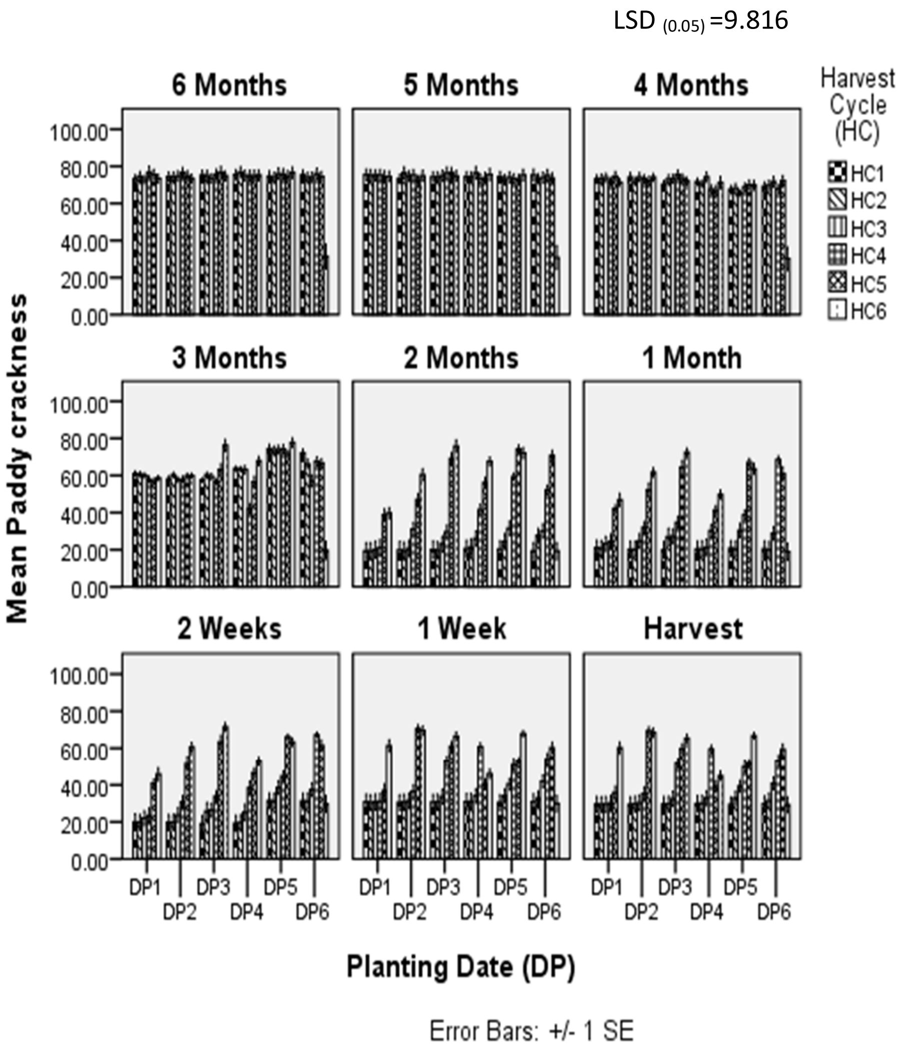

Figure 18: Effect of Planting date, Harvest cycle and Storage duration on mean paddy cracking in the Northern Savanna Agro ecological zone of Ghana. Bars represent the SEM.

4.2.12 Pearson's correlation matrix and model fit parameters between, grain moisture, grain yield, duration of storage and paddy crackness

The correlation analysis of data taken for growth and yield parameters of rice showed that grain yield had a negative relationship with paddy crackness (R^2 = -0.2370; $p < 0.001$). Grain moisture at milling had negative relationship with paddy crackness (R^2 = -0.3429; $p < 0.001$). However, storage duration was observed to have a positive relationship with paddy crackness (R^2 = 0.4194; $p < 0.001$).

Table 5: Pearson's correlation matrix between paddy crackness (PC) and, grain yield (GY), grain moisture (GM), and duration of storage (SD). Values are coefficient.

Parameters	PC
GM	-0.3429**
GY	-0.2370**
SD	0.4194**

*SD=Storage Duration, GY=Grain Yield, GM=Grain Moisture, PC= Paddy Crackness, ** = Significant at p < 0.01, * = Significant at p < 0.05*

The regression equations for all the significant relationships observed in Table 5 are provided in Table 6. Paddy crackness had R^2 values of 0.117, 0.055 and 0.176 with its relationship with grain moisture, yield and storage duration respectively. This implies that 11.7 %, 5.5 % and 17.6 % of the changes in paddy crackness can be explained by the changes in grain moisture, yield and storage duration respectively.

Table 6: Linear regressions and model fit parameters for statistically correlated (P < 0.05) parameters and duration of storage on paddy crackness

Relation	R^2	SEE	Significance level
PC = 44.41 – 1.2666(GM)	0.117	28.4	< 0.001
PC = 36.29 – 0.003136(GY)	0.055	29.3	< 0.001
PC = 4.7924(SD) + 28.78	0.176	26.1	< 0.001

GM = Grain Moisture, GY = Grain yield, PC= Paddy Crackness, SD= Storage Duration, SEE= standard error of the estimate, R^2 *= coefficient of determination*

CHAPTER FIVE

5.0 Discussion

5.1 Impact of production inputs and timing on growth parameters, moisture and yield of rice in the Northern Savannah Agro ecological zone of Ghana

5.1.1 Impact of production inputs and timing on number of tillers per stand

The results in Figure 1 are in line with that of Yoshida (1981), in relation to the effect of environmental conditions, particularly moisture and its relations to paddy growth on the tiller per meter square of rice.

The observed higher tiller numbers per stand for the treatment, N applied ½ at early tillering + ½ at panicle differentiation (F1) as compared to N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) and N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3), could be attributed to a need for higher dose of nitrogen at early growth stages compared to the lower dosages in the other treatments. This is particularly so as N is needed as constituent of enzymes and proteins, and required for enhanced cell expansion and various metabolic processes required for vigorous growth. Increase in nitrogen level as in (F1) might have assisted in greater photosynthesis, because nitrogen which is a basic constituent of protoplasm and chloroplast is required to stimulate meristematic growth and thus increase the various growth parameters including tillering.

This finding disagrees with Daftardar and Savant (1995), who observed a contrast to this finding and attributed their finding to lower N use efficiency at higher N levels. The higher tiller number per stand recorded by Second planting, + Perfume Irrigated + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) (Figure 1), is attributed to better response of the Perfume irrigated variety under the prevailing fertilizer regime and environmental conditions. For variety, this finding can be justified by the greater productivity for the given fertility, its high tillering ability, higher dry matter accumulation potential, optimum N use efficiency, more rapid crop growth rate during the flowering stage and ultimately, better compatibility with soil and atmospheric conditions (Daftardar and Savant, 1995), The different numbers of fertile tillers per unit area might be due to genetic variations. Rice cultivars differ in their potential to respond to crop fertility conditions. This result upholds the findings of Yoshida and Parao (1972), who discussed the determining impact of rice cultivar potential and environmental conditions on the number of tillers per stand.

5.1.2 Impact of production inputs and timing on number of panicles per stand

The panicles of different rice varieties varied, depending on the fertilizer regime applied to the given variety and the date of planting. The observed higher number of panicles per stand for Second Planting + Exbaika + N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) (Figure 2) shows the better comparative performance of this treatments to others. This shows that different varieties performed differently depending on nutrient regime and date of planting. N applied ½ at early tillering + ½ at panicle differentiation (F1) also produced comparable panicles per stand in all varieties as F1. Early planting also resulted in high number of panicles. The stage of panicles initiation of the early planted treatments coincided with periods of rain. Therefore, availability of soil moisture at this stage could explain the observed high number of panicles. The relations between number of tillers, effective panicles and yield are largely discussed in literature (Pyngrope *et al.*, 2017). The higher number of tillering associated with the earlier planting dates (Figure 1), correspondingly, resulted in the generation of higher number of effective tillers and panicles respectively (Figure 2). As noted by Badshah *et al.* (2014), any factor that may result in increases in effective tillers and panicle number results in increases in rice yield.

5.1.3 Impact of production inputs and timing on number of days to 50% flowering

Third Planting + Perfume Irrigated + N applied at rates of ½ at early tillering + ½ at panicle differentiation (F1) recorded the longest number of days to 50% flowering (Figure 3) because of relative differences in genetic constituents of the individual varieties that make them respond differently to nutrient and environmental conditions. At this treatment, floral induction may have been delayed in the Perfumed irrigated variety which may have resulted in the delayed number of days to flowering (Figure 3). Application of nitrogen in N applied ½ at early tillering + ¼ at panicle differentiation + ¼ at grain filling stage (F2) produced less number of days to 50% flowering than the application of nitrogen in N applied ½ at early tillering + ½ at panicle differentiation (F1) and N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3). The least number of days to 50% flowering was recorded by First Planting + Exbaika + N applied ¼ at early tillering + ¼ at panicle differentiation +¼ at heading + ¼ at grain filling stage (F3), This can be attributed to differences in genetic responses to the prevailing environmental conditions and N use efficiency of the crop. This finding is in agreement with Islam *et al*. (2007), who stated that, slow crop growth rate at earlier stages of the rice variety might be due to lower leaf development which act as the main organ of photosynthesis on which growth rate depends. However, the finding is contrary to the findings of Daftardar and Savant (1995), who stated that, early nutrients availability (mainly nitrogen) from the organic materials and inorganic fertilizer hastened plant growth and development. The finding is also in disagreement with Arnold and Taylor (2006) who also established that, N application is known to increase the levels of plant hormones which affects rice flowering.

5.1.4 Impact of production inputs and timing on number of days to maturity

The observed significant interaction of variety and fertilizer management on physiological maturity (Table 1; Figure 4) is attributed to differences in genetic constituents of the individual varieties that affect growth. Different varieties are differently impacted by different nutrient regimes to reveal the given maturity. This result is in agreement with Ali *et al*. (2000), who stated that, rice maturity is dependent on variety and has critical implication for grain yields and milling quality. In today's large variability and uncertain rainfall pattern which is noted to negatively impact rice production, Exbaika with N applied at rate of ½ at early tillering + ½ at panicle differentiation (F1), which recorded the least number of days to maturity (Figure 4) may stand as a good adaptation treatment for climate-smart rice production in northern Ghana.

5.1.5 Impact of production inputs and timing on yield

Yield increases from late planting (2600 kg/ha) to early planting (4250 kg/ha) (63%) and can be attributed to sole changes in date of planting. This provides a good opportunity for small holder farmers to earn extra income by choosing the appropriate timing for planting. As in the case of the right time of harvesting, early harvesting was associated with higher yield than late harvesting. High yield difference of 2410 kg/ha, between the early (4560 kg/ha) and late (2150 kg/ha) harvesting indicate a comparative economic gain by more than 100% by smallholder farmers when they practice early harvesting compared to late harvesting. The smallholder farmer may need to plan effectively to enable timely harvesting of paddy to avoid losses attributable to late harvesting. The observed reduction in paddy yield due to delayed harvesting as observed in this study confirms similar reports by other researchers (Efisue *et al*., 2014). This finding should appropriately inform aggregators to audit timeliness in both planting and harvesting as it forms a good basis upon which the smallholder farmers can be incentivized or resourced to gain higher economic gains from rice production. Early planting and timely harvesting will eventually result in high volumes of paddy for aggregation.

The significant interaction of planting date and harvest cycle on paddy yield (Table 1; Figure 5) shows that irrespective of the rice variety and nutrient application regime, as long as similar nutrient rates are used, planting date and time of harvest are the parameters that control rice yield. The highest yield of 4950-5500 kg/ha observed in treatments with 2^{nd}-3^{rd} planting and 2^{nd}-3^{rd} harvesting cycles show the existence of conducive yield-enhancing environmental conditions when rice is planted and harvested within these time periods. This argument is supported by the suitable growth results shown for growth season durations (Figure 1 to Figure 4) and the relation between growth variables and yield (Table 2): Thus optimum vegetative growth occurred due to prevalence of satisfactory environmental and growth conditions. This findings is in alignment with Alizadeh and Isvand (2006) who stated that, the growth season duration and temperature average have significant effects on rice yield during different growth stages; therefore, earlier planting date plays a substantial role in rice production. But it is in contrast with Slaton (2001) whose findings stated that, early planting than the optimal date leads to reduction in grain yield.

Beyond the third planting, paddy yield was in a decline as harvest cycle increased, attributable to unfavorable growth and moisture conditions with time. This occurred because majority of the panicles became immature in delayed planting and grain yield was reduced. This confirms the findings of Noorbakhshian (2003) who stated that, delayed planting caused a decrease in grain yield due to shortening of the growth period duration. Miller *et al*. (1991) also reported that, delayed planting after a certain date reduces the yield potential exponentially because sufficient and needed moisture is not obtained towards the end of the growth period.

Delayed harvesting might have resulted in low yield due to a number of reasons. Pal *et al.* (2008), noted that delayed harvesting could result in low yield due to lodging, pests and diseases build up effect, environmental and physiological problems. Early harvesting may reduce the field yield of paddy and head rice yield due to presence of immature kernels. Late harvesting may also reduce rice yield because of grain shattering and lodging. Therefore, generated knowledge on optimum time for harvesting will help tremendously when included in the harvesting plan. The observed trend indicates that early (2^{nd} and 3^{rd}) planting is favorable for the production of perfumed rice under rainfed conditions in the Northern Savannah Agro ecological zone of Ghana. Early planting is associated with higher yield, irrespective of the variety and split application of optimum fertilizer rates.

5.1.6 Impact of production inputs and timing on grain (%) moisture

Generally, harvest moisture content of paddy tended to reduce with delayed harvesting for all varieties (Figure 7). The interactive effect of planting date and harvest cycle (Figure 6), confirms findings of Siebenmorgen *et al*. (2007) who noted that, head rice yield is a quadratic function of harvest moisture content. This indicates the existence of an optimal planting date, harvest date and related harvest moisture content that can maximize head rice yield and possibly help isolate good milling quality. The significant two-way interaction of planting date and harvest cycle on grain moisture is in agreement with Martin and Daly (1993) and Conry (1995) who reported that, some factors like early sowing, optimal harvesting dates and moisture at harvest meets the twin objectives of producing higher yields and improving the quality of grain.

5.2 Impact of production inputs and timing (planting, harvesting, storage) on percentage paddy crackness in the Northern Savannah Agro ecological zone of Ghana

5.2.1 Impact of production inputs and timing on percentage (%) crackness of paddy

Significantly interactive effect ($p < 0.05$) of variety, planting date and harvest cycle (Table 4 and Figure 8) show that variety, planting date and harvest time are parameters that determine crackness at time of harvest. The existence of different shapes and sizes of grains, together with different growth conditions between plangent time of harvest must have differently combine to affect cracking.

Generally, for any variety planted at a given fertilizer application regime, crackness increased in late planting and late harvesting (Figure 8) due to unavailable moisture during plant growth, flowering and yielding. Harvesting after harvest cycle three is associated with high cracking and must be avoided. The time of harvest appears to be the most critical factor that determines cracking. Apart from Planting date 6 and Harvest cycle 6 which recorded an unexplainably low cracking, cracking in paddy generally increased with delayed planting and delayed harvesting. In contrast, early planting and early harvesting reduced grain cracking. Perfumed irrigated variety, planted at fourth planting and for all harvesting cycles consistently had lower percentage cracking except for harvest cycle six (6). As also noted by Firouzi and Alizadeh (2013), late harvesting is associated with high cracks due to the incidence of natural senescence. Kunze (2001) used the incidence of moisture differentials to illustrate the phenomenon of crack induction. When rice grains in the field reach harvest moisture (22%), the field sample may contain grains with moisture contents (MC) between 15 and 45%. Many individual grains may dry to below 15% MC during the day. Such grains can fissure on the stalk when they reabsorb moisture at night. Rapid drying produces a steep moisture gradient in the grain. As this gradient reclines after drying, the grain surface receives moisture from the interior and expands while the grain interior loses moisture and contracts. As this combination of stresses (compressive at the surface and tensile at the centre) develops with time, the grain fails in tension by pulling itself apart at its centre. The rheological aspects (stress, strain and time) cause the grain failure and cracking (Kunze, 2001).

5.2.2 Impact of production inputs and timing on cracking of paddy in Storage

At a given storage time, the date of planting and harvest time impacted paddy cracking (Figure 9 to Figure 15) due to the grain desiccation and fissuring phenomenon explained in section 5.2.1. Similar reasoning holds for the observed impact of planting date, harvest cycle and duration of storage on cracking (Figure 18). Earlier harvesting coincides with high relative humidity that slows the drying process. Slow drying of paddy is recommended to reduce cracking of rice (Akowuah *et al*., 2012; Thompson *et al*., 1990). However, the harsh harmattan condition associated with late harvesting in the northern region of Ghana at the time of harvest and storage (Padi, 2017; Oteng-Ababio *et al*., 2017) comes with it rapid desiccation of the prevailing environment that hastens drying and facilitates the incidence of desiccation, fissuring and cracking.

The longer the paddy remains on the field therefore, the longer the effect of the desiccation on the paddy, and the higher the incidence of cracking. The multi impact of natural senescence and rapid desiccation on rice cracking makes the time of harvesting an important determinant of cracking in northern Ghana. The higher the duration of storage of rice, the higher the incidence of cracking. The observed trend of impact of time of storage on crackness is in consonance with reports from other researchers (Akowuah *et al*., 2012). The observed cracking trend can be attributed to the combination of senescence and moisture stress and differential strain difference during storage. As noted by Kunze (2001), through Moisture Readsorption by Dry Rice Grains: Rice is hygroscopic. The low-moisture (dried) grain reabsorbs moisture from any source to which it is exposed. Moisture adsorbed through the grain surface causes the starch cells to expand and produce compressive stresses.

Since the grain is a "free body", compressive stresses are countered by equal but opposite tensile stresses at the grain centre. When the compressive stresses at the surface exceed the tensile strength of the grain at its centre, a fissure develops. Fissured grains usually break during milling. The sources of the grain moisture during storage range from adsorption of vapour at night and losses during the day, while the grains are in storage.

CHAPTER SIX

6.0 Conclusion and recommendations

6.1 Conclusion

Paddy cracking in aromatic rice production systems is affected by variety, time of planting, harvesting time and duration of storage. Different varieties resist cracking at different levels depending on date of planting, date of harvesting and storage duration. However, the Exbaika variety favors low cracking due to its genetic properties that makes it more resistant to fissures. For all rice varieties, irrespective of the split fertilizer application regime (as long as optimum rates of fertilizer are applied), high paddy growth and yield are favored by early planting when harvesting is not delayed. In early planting, crop growth coincides with optimum rain and growth conditions that enhances crop growth and reflects in yield. Split application regimes of optimum N-rate had no effect on yield and cracking. Again, for all treatment combinations milling within two months after harvesting is associated with lower cracking as long as the harvesting cycle does not exceed the fourth cycle. Within the first to the third harvesting cycle, therefore, crackness is low for combinations of treatments within the first month of crack determination. After the second month of storage, percentage of crackness was high approximately ninety percent (90%). Extended storage duration above three (3) months resulted in the highest cracking of paddy due to extended intermittent desiccation and remoisturization that enhances differential stresses and grains and facilitates cracking.

6.2 Recommendation

Based on findings of this research, the following recommendations are made.

1. Exbaika as a perfumed rice variety is recommended to rice farmers. The variety has the potential to yield comparably to other varieties (Agra, Gbewaa and Perfumed Irrigated) and is more resistant to cracking. Farmers who use this variety may end up obtaining premium prices from aggregators after crack determination examinations.
2. Farmers should not waste time and resources on split application of N as it has no significant effect on yield and crack reductions that are economical to farmers.
3. Early planting, early harvesting and low duration of storage are associated with higher yields and low cracking. Farmers should use these in paddy cultivation.
4. The duration of paddy storage should not exceed two (2) months. Any time after two (2) months is associated with high cracking that could result in high breakages and reduce the return on revenue for the already resource-constrained farmer.
5. This study should be replicated with more rice varieties in different ecological zones as this one was conducted in only Northern Savannah agro ecological zone with four rice varieties. There could be other varieties whose physiology may result in low cracking.

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Appendix 2: Analysis of variance for impact of production inputs and timing on tiller number per stand of perfumed rice produced in the northern savannah agro ecological zone of Ghana.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	546.702	273.351	226.60	
Replication.*Units* stratum					
Planting Date (PD)	5	166.462	33.292	27.60	<.001
Variety (VA)	3	523.889	174.630	144.76	<.001
Harvest Cycle (HC)	5	0.000	0.000	0.00	1.000
Fertilizer Management (FM)	2	4.509	2.254	1.87	0.155
PD x VA	15	759.351	50.623	41.96	<.001
PD x HC	25	0.000	0.000	0.00	1.000
V x HC	15	0.000	0.000	0.00	1.000
PD x FM	10	104.051	10.405	8.63	<.001
VA x FM	6	183.384	30.564	25.34	<.001
HC x FM	10	0.000	0.000	0.00	1.000
PD x VA x HC	75	0.000	0.000	0.00	1.000
PD x VA x FM	30	409.496	13.650	11.32	<.001
PD x HC x FM	50	0.000	0.000	0.00	1.000
VA x HC x FM	30	0.000	0.000	0.00	1.000
PD x VA x HC x FM	150	0.000	0.000	0.00	1.000
Residual	862	1039.858	1.206		
Total	1295	3737.702			

Appendix 2: Analysis of variance for impact of production inputs and timing on panicle number per stand of rice produced in the northern savannah agro ecological zone of Ghana.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	224.7200	112.3600	135.01	
Replication.*Units* stratum					
PD	5	121.5600	24.3120	29.21	<.001
VA	3	407.1022	135.7007	163.06	<.001
HC	5	0.0000	0.0000	0.00	1.000
FM	2	16.5800	8.2900	9.96	<.001
PD.VA	15	404.1378	26.9425	32.37	<.001
PD.HC	25	0.0000	0.0000	0.00	1.000
VA.HC	15	0.0000	0.0000	0.00	1.000
PD.FM	10	118.5800	11.8580	14.25	<.001
VA.FM	6	193.7311	32.2885	38.80	<.001
HC.FM	10	0.0000	0.0000	0.00	1.000
PD.VA.HC	75	0.0000	0.0000	0.00	1.000
PD.VA.FM	30	297.0289	9.9010	11.90	<.001
PD.HC.FM	50	0.0000	0.0000	0.00	1.000
VA.HC.FM	30	0.0000	0.0000	0.00	1.000
PD.VA.HC.FM	150	0.0000	0.0000	0.00	1.000
Residual	862	717.3600	0.8322		
Total	1295	2500.8000			

Appendix 3: Analysis of variance for impact of production inputs and timing on days to fifty percent flowering of perfumed rice produced in the northern savannah agro ecological zone of Ghana.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	970.446	485.223	80.22	
Replication.*Units* stratum					
PD	5	4311.682	862.336	142.56	<.001
VA	3	20311.269	6770.423	1119.27	<.001
HC	5	0.0000	0.0000	0.00	1.000
FM	2	66.228	33.114	5.47	0.004
PD.VA	15	4540.898	302.727	50.05	<.001
PD.HC	25	0.0000	0.0000	0.00	1.000
VA.HC	15	0.0000	0.0000	0.00	1.000
PD.FM	10	143.698	14.370	2.38	0.009
VA.FM	6	119.426	19.904	3.29	0.003
HC.FM	10	2.716	0.272	0.04	1.000
PD.VA.HC	75	0.0000	0.0000	0.00	1.000
PD.VA.FM	30	315.241	10.508	1.74	0.009
PD.HC.FM	50	13.580	0.272	0.04	1.000
VA.HC.FM	30	5.926	0.198	0.03	1.000
PD.VA.HC.FM	150	29.630	0.198	0.03	1.000
Residual	862	5214.221	6.049		
Total	1295	37454.219			

Appendix 4: Analysis of variance for impact of production inputs and timing on rice maturity in the northern savannah agro ecological zone of Ghana.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.00	0.00	0.00	
Replication.*Units* stratum					
PD	5	0.00	0.00	0.00	1.000
VA	3	19600.00	6533.33	586.64	<.001
HC	5	0.00	0.00	0.00	1.000
FM	2	0.00	0.00	0.00	1.000
PD.VA	15	0.00	0.00	0.00	1.000
PD.HC	25	0.00	0.00	0.00	1.000
VA.HC	15	0.00	0.00	0.00	1.000
PD.FM	10	0.00	0.00	0.00	1.000
VA.FM	6	3200.00	533.33	47.89	<.001
HC.FM	10	0.00	0.00	0.00	1.000
PD.VA.HC	75	0.00	0.00	0.00	1.000
PD.VA.FM	30	0.00	0.00	0.00	1.000
PD.HC.FM	50	0.00	0.00	0.00	1.000
VA.HC.FM	30	0.00	0.00	0.00	1.000
PD.VA.HC.FM	150	0.00	0.00	0.00	1.000
Residual	862	9600.00	11.14		
Total	1295	32400.00			

Appendix 5: Analysis of variance for impact of production inputs and timing on paddy yield in the northern guinea savannah zone of Ghana.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	5.484E+08	2.742E+08	76.48	
Replication.*Units* stratum					
PD	5	4.120E+08	8.241E+07	22.98	<.001
VA	3	1.270E+07	4.232E+06	1.18	0.316
HC	5	1.202E+09	2.405E+08	67.08	<.001
FM	2	3.934E+06	1.967E+06	0.55	0.578
PD.VA	15	9.099E+07	6.066E+06	1.69	0.047
PD.HC	25	7.763E+08	3.105E+07	8.66	<.001
VA.HC	15	8.145E+07	5.430E+06	1.51	0.093
PD.FM	10	7.790E+06	7.790E+05	0.22	0.995
VA.FM	6	3.361E+07	5.602E+06	1.56	0.155
HC.FM	10	8.722E+06	8.722E+05	0.24	0.992
PD.VA.HC	75	2.269E+08	3.025E+06	0.84	0.823
PD.VA.FM	30	2.320E+07	7.732E+05	0.22	1.000
PD.HC.FM	50	3.344E+07	6.688E+05	0.19	1.000
VA.HC.FM	30	2.944E+07	9.815E+05	0.27	1.000
PD.VA.HC.FM	150	1.591E+08	1.061E+06	0.30	1.000
Residual	862	3.090E+09	3.585E+06		
Total	1295	6.741E+09			

Appendix 6: Analysis of variance for impact of production inputs and timing on paddy moisture in the northern guinea savannah zone of Ghana.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	11362.45	5681.22	204.96	
Replication.*Units* stratum					
PD	5	2929.15	585.83	21.13	<.001
VA	3	479.81	159.94	5.77	<.001
HC	5	30009.02	6001.80	216.53	<.001
FM	2	8.61	4.31	0.16	0.856
PD.VA	15	848.82	56.59	2.04	0.011
PD.HC	25	9761.59	390.46	14.09	<.001
VA.HC	15	306.28	20.42	0.74	0.748
PD.FM	10	113.28	11.33	0.41	0.943
VA.FM	6	125.29	20.88	0.75	0.607
HC.FM	10	73.51	7.35	0.27	0.988
PD.VA.HC	75	2580.20	34.40	1.24	0.088
PD.VA.FM	30	312.18	10.41	0.38	0.999
PD.HC.FM	50	810.36	16.21	0.58	0.991
VA.HC.FM	30	491.04	16.37	0.59	0.961
PD.VA.HC.FM	150	2370.02	15.80	0.57	1.000
Residual	862	23893.47	27.72		
Total	1295	86475.05			

Appendix 7: Analysis of variance for impact of production inputs and timing on paddy crackness in the northern savannah agro ecological zone of Ghana.

Source	DF	SS	MS	F	P
Rep (A)	26	4198400	161477		
Planting (PD)	5	111307	22261	63.11	0.0000
Variety (VA)	3	12356	4119	11.68	0.0000
Fertilizer (FM)	2	178	89	0.25	0.7768
Harvest Cycle (HC)	5	666335	133267	377.80	0.0000
PD*VA	15	12242	816	2.31	0.0027
PD*FM	10	2869	287	0.81	0.6157
PD*HC	25	535862	21434	60.76	0.0000
VA*FM	6	4193	699	1.98	0.0647
VA*HC	15	14550	970	2.75	0.0003
HC* FM	10	2406	241	0.68	0.7421
PD*VA*FM	30	8608	287	0.81	0.7533
PD*VA*HC	75	71341	951	2.70	0.0000
PD*FM*HC	50	21164	423	1.20	0.1580
VA*FM*HC	30	15480	516	1.46	0.0492
PD*VA*FM*HC	150	41173	274	0.78	0.9791
Error	11205	3952521	353		
Total	11662				

Note: SS are marginal (type III) sums of squares

Grand Mean 50.766
CV 37.00

Appendix 8: Analysis of variance for impact of production inputs and timing on paddy crackness at harvest in the northern savannah agro ecological zone of Ghana.

Source	DF	SS	MS	F	P
Rep (A)	3	530823	176941		
Planting (PD)	5	18854	3771	11.84	0.0000
Variety (VA)	3	2819	940	2.95	0.0318
Fertilizer (FM)	2	368	184	0.58	0.5613
Harvest Cycle (HC)	5	194602	38920	122.18	0.0000
PD*VA	15	7558	504	1.58	0.0716
PD*FM	10	1269	127	0.40	0.9478
PD*HC	25	113977	4559	14.31	0.0000
VA*FM	6	1855	309	0.97	0.4436
VA*HC	15	6629	442	1.39	0.1451
FM*HC	10	1453	145	0.46	0.9182
PD*VA*FM	30	3176	106	0.33	0.9998
PD*VA*HC	75	25438	339	1.06	0.3349
PD*FM*HC	50	9141	183	0.57	0.9927
VA*FM*HC	30	4870	162	0.51	0.9875
PD*VA*FM*HC	150	20756	138	0.43	1.0000
Error	1292	411554	319		
Total	1726				

Note: SS are marginal (type III) sums of squares

Grand Mean 41.614
CV 42.89

Appendix 9: Analysis of variance for impact of production inputs and timing on paddy crackness at 1 week of storage in the nothern savannah agro ecological zone of Ghana.

Source	DF	SS	MS	F	P
Rep (A)	3	538510	179503		
Planting (PD)	5	19664	3933	12.33	0.0000
Variety (VA)	3	2745	915	2.87	0.0354
Fertilize (FM)	2	357	178	0.56	0.5719
Harvest Cycle (HC)	5	193557	38711	121.37	0.0000
PD*VA	15	7481	499	1.56	0.0767
PD*FM	10	1289	129	0.40	0.9451
PD*HC	25	116412	4656	14.60	0.0000
VA*FM	6	1827	305	0.95	0.4547
VA*HC	15	6697	446	1.40	0.1390
FM*HC	10	1486	149	0.47	0.9124
PD*VA*FM	30	3023	101	0.32	0.9999
PD*VA*HC	75	25380	338	1.06	0.3428
PD*FM*HC	50	9172	183	0.58	0.9925
VA*FM*HC	30	4886	163	0.51	0.9873
PD*VA*FM*HC	150	20797	139	0.43	1.0000
Error	1293	412407	319		
Total	1727	1365688			
Grand Mean	42.679				
CV	41.85				

Appendix 10: Analysis of variance for impact of production inputs and timing on paddy crackness at 2 weeks of storage in the northern savannah agro ecological zone of Ghana.

Source	DF	SS	MS	F	P
Rep (A)	3	468697	156232		
Planting (PD)	5	29270	5854	22.82	0.0000
Variety (VA)	3	4225	1408	5.49	0.0010
Fertilize (FM)	2	23	12	0.04	0.9562
Harvest Cycle (HC)	5	233250	46650	181.85	0.0000
PD*VA	15	2713	181	0.70	0.7813
PD*FM	10	1338	134	0.52	0.8758
PD*HC	25	112093	4484	17.48	0.0000
VA*FM	6	1136	189	0.74	0.6188
VA*HC	15	6245	416	1.62	0.0615
FM*HC	10	2598	260	1.01	0.4303
PD*VA*FM	30	3553	118	0.46	0.9945
PD*VA*HC	75	27170	362	1.41	0.0141
PD*FM*HC	50	8295	166	0.65	0.9733
VA*FM*HC	30	5856	195	0.76	0.8200
PD*VA*FM*HC	150	20342	136	0.53	1.0000
Error	1044	267820	257		
Total	1478				

Note: SS are marginal (type III) sums of squares

Grand Mean 43.624
CV 36.72

Appendix 11: Analysis of variance for impact of production inputs and timing on paddy crackness at 1 month of storage in the northern savannah agro ecological zone of Ghana.

Source	DF	SS	MS	F	P
Rep (A)	2	293965	146983		
Planting (PD)	5	24516	4903	17.74	0.0000
Variety (VA)	3	4306	1435	5.19	0.0015
Fertilize (FM)	2	50	25	0.09	0.9141
Harvest Cycle (HC)	5	253908	50782	183.75	0.0000
PD*VA	15	2833	189	0.68	0.8026
PD*FM	10	1781	178	0.64	0.7763
PD*HC	25	109835	4393	15.90	0.0000
VA*FM	6	1321	220	0.80	0.5727
VA*HC	15	7080	472	1.71	0.0444
FM*HC	10	3391	339	1.23	0.2692
PD*VA*FM	30	3945	132	0.48	0.9928
PD*VA*HC	75	30209	403	1.46	0.0087
PD*FM*HC	50	9663	193	0.70	0.9437
VA*FM*HC	30	6137	205	0.74	0.8438
PD*VA*FM*HC	150	22472	150	0.54	1.0000
Error	862	238230	276		
Total	1295	1013642			
Grand Mean	35.457				
CV	46.89				

Appendix 12: Analysis of variance for impact of production inputs and timing on paddy crackness at 2 months of storage in the norhern savannah agro ecological zone of Ghana.

Source	DF	SS	MS	F	P
Rep (A)	2	289076	144538		
Planting (PD)	5	52697	10539	31.42	0.0000
Variety (VA)	3	7451	2484	7.40	0.0001
Fertilize (FM)	2	243	122	0.36	0.6962
Harvest Cycle (HC)	5	328312	65662	195.75	0.0000
PD*VA	15	3738	249	0.74	0.7416
PD*FM	10	1633	163	0.49	0.8993
PD*HC	25	117148	4686	13.97	0.0000
VA*FM	6	828	138	0.41	0.8717
VA*HC	15	4195	280	0.83	0.6402
FM*HC	10	594	59	0.18	0.9978
PD*VA*FM	30	5211	174	0.52	0.9855
PD*VA*HC	75	26943	359	1.07	0.3250
PD*FM*HC	50	7749	155	0.46	0.9995
VA*FM*HC	30	7304	243	0.73	0.8594
PD*VA*FM*HC	150	19267	128	0.38	1.0000
Error	862	289152	335		
Total	1295	1161539			
Grand Mean	36.919				
CV	49.61				

Appendix 13: Analysis of variance for impact of production inputs and timing on paddy crackness at 3 months of storage in the northern savannah agro ecological zone of Ghana.

Source	DF	SS	MS	F	P
Rep (A)	2	5042	2520.91		
Planting (PD)	5	42493	8498.62	51.01	0.0000
Variety (VA)	3	674	224.51	1.35	0.2577
Fertilize (FM)	2	51	25.72	0.15	0.8570
Harvest Cycle (HC)	5	4582	916.35	5.50	0.0001
PD*VA	15	2865	191.03	1.15	0.3096
PD*FM	10	1412	141.21	0.85	0.5828
PD*HC	25	89950	3597.99	21.59	0.0000
VA*FM	6	1339	223.25	1.34	0.2366
VA*HC	15	3291	219.42	1.32	0.1847
FM*HC	10	1398	139.76	0.84	0.5912
PD*VA*FM	30	4180	139.34	0.84	0.7187
PD*VA*HC	75	20347	271.29	1.63	0.0009
PD*FM*HC	50	5795	115.89	0.70	0.9463
VA*FM*HC	30	3568	118.94	0.71	0.8717
PD*VA*FM*HC	150	19540	130.27	0.78	0.9700
Error	862	143622	166.62		
Total	1295	350149			
Grand Mean	62.061				
CV	20.80				

Appendix 14: Analysis of variance for impact of production inputs and timing on paddy crackness at 4 months of storage in the northern savannah agro ecological zone of Ghana.

Source	DF	SS	MS	F	P
Rep (A)	2	70317.8	35158.9		
Planting (PD)	5	4051.2	810.2	5.68	0.0000
Variety (VA)	3	453.5	151.2	1.06	0.3653
Fertilize (FM)	2	121.4	60.7	0.43	0.6535
Harvest Cycle (HC)	5	5915.5	1183.1	8.30	0.0000
PD*VA	15	1123.3	74.9	0.53	0.9273
PD*FM	10	634.7	63.5	0.45	0.9240
PD*HC	25	29982.9	1199.3	8.41	0.0000
VA*FM	6	145.7	24.3	0.17	0.9847
VA*HC	15	814.0	54.3	0.38	0.9838
D*HC	10	1095.9	109.6	0.77	0.6591
PD*VA*FM	30	1807.2	60.2	0.42	0.9974
PD*VA*HC	75	5847.4	78.0	0.55	0.9993
PD*FM*HC	50	5168.3	103.4	0.73	0.9221
VA*FM*HC	30	2047.0	68.2	0.48	0.9923
PD*VA*FM*HC	150	14340.0	95.6	0.67	0.9985
Error	678	96644.8	142.5		
Total	1111				

Note: SS are marginal (type III) sums of squares

Grand Mean 71.625
CV 16.67

Appendix 15: Analysis of variance for impact of production inputs and timing on paddy crackness at 5 months of storage in the northern savannah agro ecological zone of Ghana.

Source	DF	SS	MS	F	P
Rep (A)	1	118026	118026		
Planting (PD)	5	6430	1286	9.77	0.0000
Variety (VA)	3	52	17	0.13	0.9411
Fertilize (FM)	2	18	9	0.07	0.9327
Harvest Cycle (HC)	5	5640	1128	8.57	0.0000
PD*VA	15	271	18	0.14	1.0000
PD*FM	10	255	25	0.19	0.9967
PD*HC	25	32745	1310	9.95	0.0000
VA*FM	6	151	25	0.19	0.9793
VA*HC	15	201	13	0.10	1.0000
FM*HC	10	216	22	0.16	0.9984
PD*VA*FM	30	775	26	0.20	1.0000
PD*VA*HC	75	1771	24	0.18	1.0000
PD*FM*HC	50	914	18	0.14	1.0000
VA*FM*HC	30	1011	34	0.26	1.0000
PD*VA*FM*HC	150	4883	33	0.25	1.0000
Error	431	56752	132		
Total	863	230113			

Grand Mean	73.370
CV	15.64

Appendix 16: Analysis of variance for impact of production inputs and timing on paddy crackness at 6 months of storage in the northern savannah agro ecological zone of Ghana.

Source	DF	SS	MS	F	P
Rep (A)	1	101802	101802		
Planting (PD)	5	6354	1271	9.86	0.0000
Variety (VA)	3	21	7	0.05	0.9831
Fertilize (FM)	2	86	43	0.33	0.7163
Harvest Cycle (HC)	5	6958	1392	10.79	0.0000
PD*VA	15	255	17	0.13	1.0000
PD*FM	10	186	19	0.14	0.9991
PD*HC	25	31207	1248	9.68	0.0000
VA*FM	6	182	30	0.24	0.9647
VA*HC	15	335	22	0.17	0.9998
FM*HC	10	188	19	0.15	0.9990
PD*VA*FM	30	1067	36	0.28	1.0000
PD*VA*HC	75	1297	17	0.13	1.0000
PD*FM*HC	50	887	18	0.14	1.0000
VA*FM*HC	30	1108	37	0.29	0.9999
PD*VA*FM*HC	150	4197	28	0.22	1.0000
Error	431	55573	129		
Total	863	211704			
Grand Mean	73.749				
CV	15.40				

Appendix 17: Analysis of variance for impact of Planting date, Harvest cycle and Storage duration on mean paddy cracking in the Northern Savanna Agro ecological zone of Ghana.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	8	165394.8	20674.3		
Residual	-6	0.0			
Planting Date (PD)	5	88364.0	17672.8	117.50	<.001
Storage Duration (SD)	8	2599710.9	324963.9	2160.56	<.001
Harvest Cycle (HC)	5	467867.9	93573.6	622.13	<.001
PD.SD	40	91296.9	2282.4	15.17	<.001
PD.HC	25	545362.7	21814.5	145.04	<.001
SD.HC	40	578366.8	14459.2	96.13	<.001
PD.SD.HC	200	193454.5	967.3	6.43	<.001
Residual	3562	535751.7	150.4		
Total	3887	5265570.2			