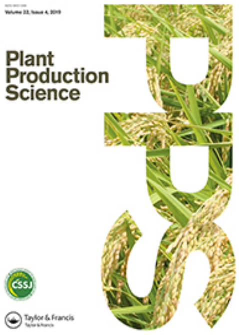


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# Multidisciplinary assessment of agricultural innovation and its impact: a case study of lowland rice variety WITA 9 in Côte d'Ivoire

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**ABSTRACT**

Information on comprehensive evaluation of agricultural innovations is often limited. This study provides an overview of multidisciplinary evaluation of a lowland rice variety, WITA 9 (released in Côte d'Ivoire in 1998), with respect to its agronomic performance, grain quality, resistance to diseases, adoption by farmers, impact on productivity and farmers' income, and marketability. WITA 9 had the highest paddy yield among the tested varieties including an international check (IR 64) and recently developed varieties adapted to this country. WITA 9 had a higher amylose content (26–28%) than others tested. This study confirmed its resistance to bacterial leaf blight, *Rice yellow mottle virus* (RYMV), and rice blast. A household survey showed that the adoption rate was 24%, its paddy yield advantage was 0.7 t ha$^{-1}$, and its adoption increased farmer's income by US$ 91 ha$^{-1}$ per season. A market study showed that consumers' willingness to pay was higher for WITA 9 than any other locally produced rice variety and comparable to imported rice in one of two markets. We conclude that WITA 9 is an ideal innovation for enhancing productivity and rice import substitution in Côte d'Ivoire. An effective seed delivery system and enhancing farmers' and consumers' awareness of this variety are vital for accelerating impact.

Multidisciplinary assessment of agricultural innovation and its impact: A case study of lowland rice variety WITA 9 in Côte d'Ivoire

- Agronomic performance
- Grain quality
- Resistance to selected diseases
- Adoption and impact in farmers' fields
- Marketability

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## 1. Introduction

There is a large gap between supply from local rice production and consumption in Côte d'Ivoire, as in most West African countries, and imported rice accounts for about 50% of the country's rice consumption (United States Department of Agriculture Foreign Agricultural Service, 2016). As heavy dependence on importation will not lead to food security (Seck, Touré, Coulibaly, Diagne & Wopereis, 2013), the country has launched an ambitious program for rice sector development (Ministère de l'Agriculture et du Développement Rural [MINADER], 2012) through the creation of special agency for rice – Office National de Développement de la Riziculture (ONDR) – that contributes to increased local rice production. Such an increase requires improved rice yield, better grain quality, and expansion of the area under cultivation (Saito, Dieng, Toure, Samodo, & Wopereis, 2015; Saito et al., 2013).

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Lowland (rainfed and irrigated) and upland rice accounted for 28% and 72% of the total rice area (0.87 million ha), respectively, in 2016 (ONDR, 2017). National average paddy yield was 2.3 t ha$^{-1}$, which is around half of the global average yield. This low yield was due to various constraints, including abiotic and biotic stresses, and suboptimum crop management practices (Diagne et al., 2013; MINADER, 2012; Niang et al., 2017; Saito et al., 2013, 2019, 2017; Tanaka et al., 2017; Tanaka, Saito, Azoma & Kobayashi, 2013; Tsujimoto, Muranaka, Saito & Asai, 2014).

To alleviate abiotic and biotic stresses and enhance domestic rice production in sub-Saharan Africa, research and development activities have developed and delivered new rice varieties (Saito, Asai, Zhao, Laborte & Greiner, 2018; Saito, Azoma & Sie, 2010; Saito, Azoma & Sokei, 2010; Saito, Sokei & Wopereis, 2012; Sikirou et al., 2015; Tollens et al., 2013). Breeding efforts have been focused on the development of varieties that have higher paddy yield as well as resistance to abiotic and biotic stresses, with limited focus on grain quality. One product from these efforts is the lowland variety WITA 9 (TOX 3058-28-1-1-1), which was released in Côte d'Ivoire in 1998 (MINADER, 2002), where *Rice yellow mottle virus* (RYMV) is one of the main biotic constraints in lowland rice production. The variety is sometimes called 'Nimba' (name of the highest mountain along the Côte d'Ivoire–Guinea–Liberia border) or 'Easy money maker.'

WITA 9 was developed from a cross between IR 2042-178-1 and CT 19 carried out in 1984 by the International Institute of Tropical Agriculture (IITA) (West Africa Rice Development Association [WARDA], 1996). This line was received by the West Africa Rice Development Association (WARDA; renamed Africa Rice Center [AfricaRice] in 2009) and screened for several traits including yield, iron toxicity, drought, RYMV and bacterial leaf blight (BLB, caused by *Xanthomonas oryzae* pv. *oryzae*) resistance, and found acceptable for all these traits, especially RYMV resistance, which was the main criterion for its selection (Singh, Williams, Ukwungwu & Maji, 2004). Along with other breeding products, this line was then evaluated by national agricultural research institutes of West Africa and WARDA in regional trials (WARDA, 1996).[1]

On the basis of data obtained in the regional trials over 4 years, TOX 3058-28-1-1-1 was identified as the 'best bet' elite line in RYMV-affected areas. In 2010, WITA 9 was also released in Niger, where RYMV is also a major constraint to rice production (Oludare, Tossou, Kini & Silué, 2016). Resistance of WITA 9 to RYMV was further confirmed by other studies (Amancho et al., 2008; Bouet & Amancho, 2010; Guei & Traore, 2001; Zouzou, Kouakou, Koné & Souley, 2008) and was shown to be inherited from CT 19 (Amancho, Diallo, Kouassi, Bouet & N'guessan, 2009). Although this variety was also identified as susceptible in some localities in Côte d'Ivoire and to particular RYMV isolates (Amancho et al., 2009; Bouet, Amancho, Kouassi, & Auguete, 2013), its overall resistance to RYMV is considered as acceptable by farmers (Bouet & Amancho, 2010).

The period following the release of WITA 9 was characterized by social unrest in Côte d'Ivoire, resulting in the relocation of AfricaRice research activities elsewhere. Nevertheless, WITA 9 was successfully diffused via large-scale dissemination of its seed by initiatives of the Government of Côte d'Ivoire and through support from a wide range of development organizations and governments of other countries (e.g. World Bank, World Food Programme, Food and Agriculture Organization of the United Nations, United Nations Development Programme, Government of Japan, United States Agency for International Development). AfricaRice has contributed to seed production together with its public and private partners, and strengthened the seed system. For example, AfricaRice and its partners produced a total of 735 metric tons of foundation seed of WITA 9 over the period 2011–2015.

Although such efforts to disseminate WITA 9 were reported by local media such as newspapers, the success story of the upland 'New Rice for Africa' (NERICA) varieties diverted attention from the success of WITA varieties that preceded the NERICA varieties; there have been many studies and publications related to NERICA varieties (e.g. M. Matsunami, Matsunami & Kokubun, 2009; Saito et al., 2018; Saito, Fikuta, Yanagihara, Ahouanton, & Sokei, 2014; Saito et al., 2012; Sekiya et al., 2013; Watanabe, Futakuchi, Jones & Sobambo, 2006). As a result, the agronomic characteristics, adoption and impact in farmers' fields, and marketability of WITA 9 have not been studied until recently. Such information could provide insights for future breeding efforts and seed delivery systems in West Africa. In this region, urban consumers get used to eating imported rice, so it is important to examine whether locally produced rice is preferred by them (Demont, Fiamohe & Kinkpé, 2017). Locally produced rice is usually discounted on the market, which is a disincentive to rice farmers (Demont et al., 2017; Fiamohe, Demont, Saito, Roy-Macauley & Tollens, 2018).

This paper provides an overview of a multidisciplinary evaluation of the lowland rice variety WITA 9 as an example of a successful agricultural innovation. The specific objectives were to: (i) evaluate its agronomic performance, grain quality, and resistance to selected diseases; (ii) assess farmers' adoption and the impact of this variety on on-farm productivity and income; and (iii) examine its marketability in urban markets. The paper concludes by discussing results across the different studies in an integrated manner and important implications for the development of rice varieties and the requirements for their successful diffusion in West Africa.

## 2. Material and methods

Five studies were carried out to evaluate the agronomic performance, grain quality, resistance to diseases, adoption and impact in farmers' fields, and marketability of WITA 9. The approaches and methodologies used for each evaluation are described below.

### *1.1. Agronomic performance*

Agronomic performance of WITA 9 in comparison with other varieties and varietal response to nitrogen fertilizer were assessed through field trials conducted during the 2014 rainy season and the 2015 dry season at the AfricaRice research station of M'bé (07°52′ N, 05°6′ W) near Bouaké, Côte d'Ivoire. The rainfall pattern is bimodal with two rainfall periods from April to mid-July and September to October, and a dry season from November to March. The soil at the experimental site was classified as a sandy clay loam Inceptisol.

Five lowland rice varieties (Bouaké 189, Bouaké-Ameliore [referred as Bouaké-AM], IR 64, NIL 130, and WITA 9) were grown under irrigated lowland conditions. Bouaké 189, which has been released and is widely grown in lowland conditions in Côte d'Ivoire, served as check variety and also as susceptible check for RYMV. Bouaké-AM was developed by the Centre National de Recherche Agronomique (CNRA), the national agricultural research center of Côte d'Ivoire, by introgressing RYMV-resistance gene *rymv1–2* into Bouaké 189 to improve its RYMV resistance (Bouet & Amancho, 2010). IR 64 has the RYMV-susceptible allele *rymv1–1* and is used widely internationally as an RYMV-susceptible check (Oludare et al., 2016). NIL 130 is a near-isogenic line developed by AfricaRice (Jaw, Ndjiondjop, Akromah & Séré, 2012) that harbors the resistance allele *rymv1–2* in the IR 64 background.

The experiment was designed with two nitrogen fertilizer treatments (main plot) and five varieties (subplot) in a split-plot design with four replications in each season. Subplot size was 20 $m^2$. Fertilizer treatments were two levels of nitrogen application consisting of 0 kg N $ha^{-1}$ (0N) and 120 kg N $ha^{-1}$ (120 N). Land was plowed using a power tiller prior to transplanting. Phosphorus (P) and potassium (K) were applied basally at the rates of 30 kg P and 50 kg K $ha^{-1}$ in all plots. N fertilizer as urea was applied in two splits with two-thirds of the total dosage of N basally incorporated at transplanting and the remaining third at panicle initiation. Sowing was done on 21 May 2014 and 26 January 2015. Seedlings (21 days old) were transplanted at 20 cm × 20 cm spacing with two seedlings per hill. All plots were hand-weeded when required. At maturity, grain yield, total aboveground dry biomass (straw was sun-dried for 2 days, followed by oven-drying at 65°C for 48 h), and harvest index (HI) were assessed from a harvest area of 6 $m^2$ in each subplot. Rice grain yield was corrected to 14% moisture content. Plant height and yield components were determined from 10 randomly selected hills.

Statistical analyses were carried out using the mixed model procedure with the restricted maximum likelihood method (REML) for variance estimates over years (SAS Institute, 2001). Fixed effects were year, fertilizer treatment, and variety, while replication was a random effect. Mean separation was performed using the SAS LSMEANS test (probability of difference [PDIFF]) at $P \leq 0.05$.

### *1.2. Grain quality*

Grain quality analysis was carried out on three rice varieties (Bouaké 189, IR 64, and WITA 9) grown under irrigated lowland conditions on the AfricaRice research stations in Cotonou, Bénin (6°25′ N, 2°20′ E) and Ndiaye, Senegal (16°14′ N, 15°13′ W) with two trials per country. In Bénin, the trials were conducted during the same cropping season (August–December) in both 2011 and 2012. In Senegal, the first trial was established in February 2012 and the second trial in July 2012. An alpha-lattice design was used with two replications in Bénin and three replications in Senegal. Plot size was 2.6 m × 2 m. Rice seedlings were transplanted at 18–21 days after sowing at a density of 20 cm × 20 cm with one plant per hill. Compound NPK fertilizer (15–15–15 or 10–20–20) was applied at 200 kg $ha^{-1}$ at transplanting and 40 kg N $ha^{-1}$ as urea 4 weeks later. Weeds were removed manually, when required. Harvested paddy was dried in the sun to a moisture content of 18% and then dried in the shade to between 12% and 14% moisture content. The dried samples were kept in paper bags and equilibrated at laboratory temperature for 1 month prior to grain quality evaluation.

Rice paddy samples were dehusked in a THU-34A Satake Testing Rice Husker (Satake, Japan) to obtain brown rice, which was then polished in a Ricepal 32 (Yamamoto Co., Japan) rice polisher. The milled rice was then separated into whole and broken grains using a Satake Test Rice Grader (Satake, Japan). Head-rice yield was calculated using the formula:

$$\text{Head rice}(\%) = \frac{\text{weight of whole grains}}{\text{weight of paddy}} \times 100$$

Chalkiness and grain dimensions were measured using the S21 Rice Statistic Analyzer (LKL Technologia, Brazil). Chalkiness was determined by processing the captured images and applying the 'basic filter – chalky distribution.' The percentage of total chalky area for the samples was recorded and reported as the sample percentage chalkiness. The grain dimensions were determined by applying the 'advanced filter – length distribution' of the software. The grain length and width were then recorded and the length–width ratio calculated.

Apparent amylose content was measured using the standard iodine colorimetric method ISO 6647-2-2011. The pasting properties of rice flour were measured for all samples using a Rapid Visco Analyzer (RVA) Super 4 (Newport Scientific, Warriewood, Australia) and Thermocline for Windows (TCW3) software. The general pasting method 162 (ICC, 2004) for flour samples was used.

## 1.3. Diseases

### 1.3.1. Bacterial leaf blight

Five varieties (Bouaké 189, Bouaké-AM, IR 64, NIL 130, and WITA 9) were screened for resistance to bacterial leaf blight (BLB), caused by *Xanthomonas oryzae* pv. *oryzae*, in a screen house with semi-controlled temperature (30 ± 7°C). The trial was conducted at the AfricaRice research station in Cotonou, Bénin (6°25′ N, 2°20′ E). Seedlings (35 days old) were raised in 1-liter pots filled with autoclaved soil collected on the campus. Three pots were then sown with 4–5 seeds for each variety–isolate combination and there were three replications. Plants were watered and each pot was fertilized with 0.5 g N-$P_2O_5$-$K_2O$ (15-15-15) at sowing and 0.5 g urea 21 days after sowing. Plants were then inoculated with one of three BLB isolates (ABB1, ABB 40, and ABB 41) collected on wild rice (*Oryza longistaminata*) near Tanguiéta (northern Bénin) following the method of Gonzales et al. (2007). To this end, three or four seedlings per variety and 3–4 leaves per plant were inoculated with the isolate. Control plants were inoculated with sterile distilled water.

Inoculated plants were then kept for 15 days in a greenhouse. Disease severity was assessed at 15 days after inoculation (DAI) by first measuring the length of the lesion developed on each inoculated leaf and then the total length of the leaf. The mean percentage of lesion length to leaf length (disease severity or DS) was then calculated for each variety–isolate combination. Finally, a scale developed by AfricaRice (Agnimonhan, Sanya, Afolabi, Oludare & Silué, 2016) was used to assess the resistance or susceptibility of each variety. On this scale, varieties were categorized as very resistant (VR) for DS < 1.0%; resistant (R) for 1.0 ≤ DS ≤ 12.5%; moderately resistant (MR) for 12.5 < DS ≤ 25.0%; moderately susceptible (MS) for 25.0 < DS ≤ 50.0%; and susceptible (S) for DS > 50%. Analysis of variance (ANOVA) was carried out and mean separation was done using the new Duncan's Multiple Range Test (DMRT) at 5% level of probability.

### 1.3.2. Rice Yellow Mottle Virus (RYMV)

Three strains of RYMV (RBe 10/10, RBe 11/24, and RBe 11/41) that represent the Béninese and Togolese virus diversity (Oludare et al., 2016) were used for screening the varieties for disease resistance. The trials were conducted at the AfricaRice research station in Cotonou, Bénin (6°25′ N, 2°20′ E). Inoculation was done according to the protocol described by Oludare et al. (2016). For each variety tested, two pots with four 30-day-old plants were inoculated with each strain or sterile distilled water (as control). There were three replications. Disease severity (DS) was scored at 21 and 42 DAI using the severity scale of 0–9 (Konaté, Traoré & Coulibaly, 1997) in which 0 indicates the absence of symptoms and 9 heavily attacked leaves with typical symptoms and some plant death. Mean DS indices were then calculated as indicated by Oludare et al. (2016) and varieties were then classified as follows: resistant (R): 0 ≤ DS ≤ 10.0%; moderately resistant (MR): 10.0 < DS ≤ 25.0%; moderately susceptible (MS) for 25.0 < DS ≤ 40.0%, and susceptible (S) for DS > 40%.

### 1.3.3. Blast resistance

For blast screening trials, 3-week-old seedlings raised in a screen house on the AfricaRice research station in Cotonou, Bénin (6°25′ N, 2°20′ E) were used. For this purpose, seeds were sown in 15-row trays having 10 holes per row. Each row had 10 seedlings and was planted with one variety; one seed was sown in each hole. In addition to the varieties to be tested, Maratelli and CO 39 served as blast-susceptible checks, while Moroberekan and Tetep served as blast-resistant controls. Seven blast isolates (BN0013, BN0050, BN0066, BN82, BN00119, BN00202, and BN00204) from Bénin (of the nine considered to represent Béninese blast pathogenicity diversity as described by Odjo, Silué & Tharreau, 2018) were spray-inoculated until spray ran off the plants. Between them, these isolates overcome 36 single or pyramided resistance gene (including *Pi5, Pli7, Pi9, Pi12, Pi19, Pita-2, Pb1, Pib, Pi1+ Pi1b+Pi33*) of 54 blast differential and traditional varieties. Inoculums were calibrated to 30,000 spores $ml^{-1}$. The inoculated plants were then kept in a humid chamber for 24 h, and then in a screen house for 6 days. Scoring of the individual plants was done 7 days post-inoculation using the 0–5 scale described by Silué, Notteghem and Chaume (1992) in which 0 corresponds to healthy plants with no visible symptoms and 5 to heavily attacked plants showing lesions with typical susceptibility features (numerous lesions with no brown but purple-grey margins, often with dead plants). Data on disease score for individual plants were then averaged for each variety–isolate combination and varieties were categorized as resistant (R) for DS ≤ 2.0; moderately resistant (MR) for 2.0 < DS ≤ 3.0; moderately susceptible for 3.0 < DS ≤ 4.0; and susceptible (S) for DS > 4.0. ANOVA was carried out and mean separation was done using the new DMRT at 5% level of probability.

### 1.4. Adoption and impact study

Socioeconomic data – including household size, age of farmers, education level, gender, rice variety used, and rice production cost and revenues – were collected in 2013–2014 in the region of Gagnoa, which is located in south-central Côte d'Ivoire, and which CNRA and its partners have identified as a priority intervention area for rice research and development in the country. A two-stage random sampling technique was used to select the households to be interviewed. In the first stage, villages were stratified using the following criteria: (1) rice-growing environments, (2) village accessibility, and (3) dominant crop. Accessibility in this context is related to the road conditions to access the village. Because of the high intensity of field activities associated with the research, villages with very limited access throughout the year were not selected. Thirty-two villages were selected in the region. At the second stage, stratified random sampling was carried out for households using, as selection criteria, the rice activities and the gender of the household head. A list of all households in each village was made. Ten households were randomly selected from each of the 32 villages with some adjustments made for including at least 30% of the minority gender. In total, 320 rice-farming households were selected. However, due to the unavailability of some farmers, only 304 households were interviewed. The counterfactual outcome framework described by Diagne and Demont (2007) and Arouna, Lokossou, Wopereis, Bruce-Oliver and Roy-Macauley (2017) was used to assess the adoption rate and impact of WITA 9. In this study, a farmer was considered as an adopter if they had grown WITA 9 at least three times before the survey. Outcomes selected for this study were yield and income. In the counterfactual framework, impact assessment consists of estimating the average situation of adopters of the improved variety (WITA 9) had they decided not to adopt. Unfortunately, one cannot observe the two situations for the same farmer: one cannot observe what would have been the outcome of an adopter if they had not adopted (or the converse). This missing value is known as the counterfactual and the impossibility of observing it constitutes the key challenge of impact assessment. A simple method to deal with this would be to determine the difference for the selected outcome between adopters and non-adopters. However, the interpretation of this difference (known as the naïve method) as a causal relationship of adoption raises many problems. If the difference observed between two groups, adopters and non-adopters, was positive or negative, it does not necessarily indicate a causal relationship. Indeed, a part of the difference may exist before the adoption. The difference may be due to both observed and unobserved characteristics. An unbiased difference will then be determined if the groups of adopters and non-adopters are similar, and the observable difference is solely the adoption of WITA 9. To solve the problem of selection bias and generate unbiased impact, Endogenous Switching Regression (ESR) was used. Unlike other models, such as the propensity matching methods, ESR allows accounting for selection bias due to both observable and unobservable characteristics. To account for observed characteristics, ESR uses two regime equations for adopters and non-adopters. The selection equation is the adoption model estimated with the probit model. The selection equation is linked to the two regime equations through the instrumental variable method. Instrumental variable method is used to account for selection due to unobserved factors. It supposes the existence of at least one instrument that influences the adoption but not the outcome variables (yield and income). In this study, 'belonging to a farmer association' was used as instrumental variable. Indeed, belonging to farmer association as a source of information and access to input and output markets may affect the adoption of WITA 9, but it is directly related neither to the yield nor the income. ESR model was used to estimate the average treatment effect on the treated (ATET), which is the impact on a farmer randomly selected in the population of adopters.

### 1.5. Market study

In the framework of identifying the rice varieties that can compete with imported rice in the main African urban markets dominated by the consumption of imported rice, market studies were carried out in the main urban markets in Gagnoa and Man, Côte d'Ivoire. Man is located in the west of the country and has also been identified by CNRA and its partners as a priority intervention area for rice research and development. It is noted that the adoption and impact study was not conducted in Man due to the fact that CNRA focuses on upland rice research in breeding and agronomy in Man. Prior to the study, different rice varieties were purposely selected including WITA 9 which is most commonly grown and consumed in Gagnoa.

The study was conducted to identify urban consumers' preference and elicit their willingness to pay (WTP) for both locally produced and imported rice. Theoretically, consumers' behavior toward a product is determined by their characteristics and the product's attributes (Lancaster, 1966). This theory states that utility or satisfaction is derived from the characteristics of the products rather than the products themselves. In that respect, data were collected using experimental auction method in Gagnoa and Man in 2014 and 2016, respectively. Vickrey's second price auction method was used in combination with the endow-and-upgrade method (Lusk & Shogren, 2007; Vickrey, 1961). Details of the auctions are given by Demont et al. (2017).

In each market, the following three types of rice were identified.

(1) Poor-quality locally produced rice (standard rice) usually sold on the market at lower price ('Malo Woussou' in Gagnoa and 'Saioua' in Man).
(2) Alternative locally produced rice upgraded with superior quality attributes: 'Bété Rice' and WITA 9 in Gagnoa, and Danane and Bouaké-AM in Man. On the urban markets, all these alternative rices were more expensive than the standard rice. It is noted that in addition to two varieties in Man, WITA 9 from Gagnoa was included for this evaluation and WITA 9 is not popular in markets in Man.
(3) Alternative imported rice – the most popular imported rice ('Papillon' in Gagnoa and 'Uncle Sam' in Man).

Some 150 and 120 urban shoppers ('consumers') were randomly selected in Gagnoa and Man, respectively, to assess consumers' preferences for different types of rice, examine their WTP for the alternative types of rice in comparison with standard rice, and identify their decision criteria for purchasing. These consumers were those responsible for selecting the rice types for their own household consumption. Standard rice price was US$ 0.54 kg$^{-1}$ and US$ 0.60 kg$^{-1}$ in Gagnoa and Man, respectively. WTP is defined as the absolute difference between the price that consumers indicated they were willing to pay for alternative rice and the standard rice price. In each city, 10 experimental auctions were performed, with an auction having 12 to 15 consumers. In each auction, four rounds were organized and consumers evaluated the different rice types as follows.

(1) Pre-tasting round, in which consumers were interviewed after visual assessment of the physical characteristics of uncooked rice.
(2) Post-tasting round, in which consumers were interviewed after assessment of the sensory attributes (aroma, taste, texture, and other characteristics) of the cooked rice.
(3) Collective round, in which, after the assessment of both uncooked and cooked rice, consumers were requested to gather in groups of four or five around a table and discuss to reach consensus on the collective WTP for each of the alternative rice types.
(4) Post-collective round, in which individual consumers assessed the different rice types individually after the group discussion.

During each round, the WTP was measured as the maximum amount that consumers were willing to add to the standard rice price to buy the alternative rice (Demont et al., 2017). Each auction ended with a short survey to collect socio-demographic data from each consumer. Descriptive statistics were used to show consumers' socio-demographic information and decision criteria for purchasing rice types.

Based on Lancaster's (1966) approach, a regression analysis with robust specification correcting eventual heteroscedasticity was performed to identify the determinants of the revealed price premium for WITA 9 in comparison with imported rice. Imported rice was selected as it is dominant in most urban markets in West Africa (Fiamohe et al., 2018) and we aimed to identify the detriments of the revealed price premium for reversing this trend. The revealed price premium for WITA 9 was computed as the difference between the WTP for WITA 9 divided by the price of the standard rice and the WTP for imported rice divided by the price of standard rice obtained in the post-collective round in each auction (see Demont et al., 2017). The socio-demographic variables included in the regression as independent variables were gender, ethnic group, education level, age, income per capita, household size, and WITA 9 producing area. Mandé is one of the main ethnic groups in Côte d'Ivoire, and traditional rice cultivation in West Africa can be traced back to the Mandé ethnic group (Olson, 1996; Sharma, 2010). We assume that consumers with Mandé lineage tracing back to the first domesticators of African rice will tend to pay higher price premiums for domestic rice. We included a dummy variable indicating whether it is a WITA 9 producing area or not (Gagnoa = 1; Man = 0). In addition, taste premium and word-of-mouth (WOM) communication premium were also assessed. Taste premium is computed, following Demont et al. (2017), as:

$$\frac{(\text{WTP in post-tasting round}) - (\text{WTP in pre-tasting round})}{(\text{standard rice price})}$$

Positive taste premium indicates that tasting can increase consumers' WTP.

The WOM communication premium is computed as:

$$\frac{(\text{WTP in post} - \text{collective round}) - (\text{WTP in post} - \text{tasting round})}{(\text{standard rice price})}$$

Positive WOM communication premium indicates that communication among consumers can increase their WTP. To cancel the effect of income on the WOM and taste premiums, we also added the ratio of taste and WOM premiums relative to income (taste per income and WOM per income). Finally, consumer requirements in terms of rice attributes were also included in the model.

## 3. Result and discussion

### 3.1. Agronomic performance

*F* ratios were the highest for the fertilizer treatments for all the traits (Table 1) except for days to heading and harvest index. N application increased paddy yield, aboveground biomass, plant height, number of panicles, and number of grains per panicle by an average of 100%, 121%, 18%, 98%, and 63%, respectively, for the mean of the five varieties (Table 2; 5.8 vs. 12.8 t ha$^{-1}$ for aboveground biomass and 97 vs. 158 for number of grains per panicle). There was no significant difference in aboveground biomass among the five varieties (data not shown). For all the traits, variety × season and variety × fertilizer interactions were significant, except for variety × fertilizer interaction on aboveground biomass, days to heading, and number of grains per panicle, and variety × season interaction on aboveground biomass and number of panicles per m$^2$ (Table 1). By contrast, variety × season × fertilizer interaction was significant only for plant height (Table 1). Mean comparisons were made for traits which had variety × fertilizer or variety × season interaction (Tables 2 and 3, respectively).

WITA 9 showed best yield performance in both seasons, the others having lower yield in at least one of the two seasons (Table 3). While WITA 9 had high yield both with and without fertilizer, NIL 130 and IR 64 had yields similar to that of WITA 9 only when N was applied (Table 2). Good adaptation of WITA 9 to low-input conditions found in this study is in agreement with a previous study in Ghana (Ofori, Hisatomi, Kamidouzono, Masunaga & Wakatsuki, 2005). In that study, WITA 9 showed the highest yield among the varieties tested under low-input irrigated and rainfed lowland conditions. Yield response to N fertilizer application differed among the varieties, ranging from 2.6 to 3.7 t ha$^{-1}$. NIL 130 had the highest response to N fertilization, followed by IR 64 and WITA 9. These three varieties tended to have shorter plants than the other varieties. Thus, plant height (short) might contribute to greater responsiveness to N fertilizer application. Saito et al. (2010) found the same negative relationship between plant height and yield response to N fertilizer in lowland rice conditions in Bénin. Apart from this higher responsiveness to N fertilizer, WITA 9 characteristics included intermediate number of days to heading and number of panicles m$^{-2}$, large number of grains per panicle, and high harvest index, which are often observed in high-yielding inbred materials developed by IRRI (Laza, Peng, Akita & Saka, 2003, 2004; Peng & Khush, 2003).

### 3.2. Grain quality

Head-rice yield of IR 64 was significantly higher than that of the other two varieties in both countries (Table 4). Based on the grain length and length-to-width ratio, WITA 9 had slightly shorter grains. At both sites, IR 64 recorded lower incidence of chalkiness than the others.

The grain quality traits that distinguished WITA 9 from both Bouaké 189 and IR 64 were the apparent amylose content and paste viscosity, which together reflect the eating and functional use of rice varieties (Graham-Acquaah, Manful, Ndindeng & Tchatcha, 2015; Manful, Abbey & Coker, 2009). WITA 9 had higher amylose content, and higher peak and setback viscosities than the others. These characteristics indicate that WITA 9 is likely to be harder, fluffier, and much less sticky on cooking than the

**Table 1.** *F* ratios from the combined analysis of variance for paddy yield, aboveground biomass, harvest index, plant height, days to heading, number of panicles, and number of grains per panicle for six varieties evaluated under two fertilizer treatments over two seasons at M'bé, Bouaké, Côte d'Ivoire (2014 rainy season and 2015 dry season).

| Source of variation | d.f. | Yield | Aboveground biomass | Harvest Index | Height | Days to 50% heading | No. panicles per m$^2$ | No. grains per panicle |
|---|---|---|---|---|---|---|---|---|
| Season | 1 | 17.41** | 0.37 | 49.99** | 32.99** | 492.78** | 1.78 | 2.45 |
| Fertilizer | 1 | 1304.36** | 259.01** | 0.06 | 426.45** | 0.56 | 241.66** | 222.60** |
| Season by fertilizer | 1 | 4.33* | 1.71 | 17.36** | 0.08 | 15.35** | 0.05 | 0.01 |
| Variety | 4 | 4.79** | 0.23 | 9.40** | 59.04** | 376.32** | 15.47** | 19.55** |
| Variety by season | 4 | 6.92** | 1.26 | 4.71** | 8.04** | 13.45** | 0.76ns | 3.16* |
| Variety by fertilizer | 4 | 6.02** | 0.15 | 3.47** | 4.40** | 2.14 | 3.40* | 2.10 |
| Variety by season by fertilizer | 4 | 0.87 | 1.01 | 0.49 | 3.38* | 1.14 | 1.33 | 2.46 |

*, ** denote statistical significance at the 5% ($P < 0.05$) and 1% ($P < 0.01$) levels, respectively.

**Table 2.** Yield, harvest index, plant height, and number of panicles per $m^2$ for five rice varieties evaluated under two fertilizer treatments (0 and 120 kg N $ha^{-1}$) at M'bé, Bouaké, Côte d'Ivoire in 2014 rainy season and 2015 dry season.

| | Yield (t $ha^{-1}$) | Harvest index | Height (cm) | No. panicles per $m^2$ |
|---|---|---|---|---|
| *0N* | | | | |
| Bouaké 189 | 3.1 de | 0.54 abc | 92 c | 124 e |
| Bouaké-AM | 3.0 de | 0.52 cd | 97 b | 129 e |
| NIL 130 | 2.5 f | 0.48 f | 77 e | 179 d |
| IR 64 | 2.9 e | 0.50 def | 88 d | 157 de |
| WITA 9 | 3.4 d | 0.57a | 88 d | 129 e |
| Mean | 3.0 | 0.52 | 88 | 143 |
| *120N* | | | | |
| Bouaké 189 | 5.8 bc | 0.53 d | 109 a | 223 c |
| Bouaké-AM | 5.6 c | 0.49 ef | 119 a | 232 c |
| NIL 130 | 6.2 a | 0.52 cde | 96 b | 361 a |
| IR 64 | 6.0 ab | 0.53 bcd | 106 a | 305 b |
| WITA 9 | 6.3 a | 0.56 b | 99 b | 292 b |
| Mean | 6.0 | 0.53 | 104 | 283 |

Note: Within columns, means followed by the same lowercase letter do not differ significantly by least significant difference (LSD; $P < 0.05$).

**Table 3.** Yield, harvest index, plant height, days to heading, and number of grains per panicle for five rice varieties evaluated at M'bé, Bouaké, Côte d'Ivoire in 2014 rainy season and 2015 dry season.

| | Yield (t $ha^{-1}$) | Harvest index | Height (cm) | Days to 50% heading | No. grains per panicle |
|---|---|---|---|---|---|
| *2014 wet season* | | | | | |
| Bouaké 189 | 4.4 cde | 0.57 a | 100 b | 115 b | 126 bcd |
| Bouaké-AM | 4.3 def | 0.55 a | 102 ab | 117 a | 139 ab |
| NIL 130 | 4.8 ab | 0.54 a | 90 d | 105 e | 109 cd |
| IR 64 | 4.8 ab | 0.53 a | 101 ab | 109 d | 127 bc |
| WITA 9 | 5.0 a | 0.57 a | 97 c | 113 c | 153 a |
| Mean | 4.7 | 0.55 | 98 | 112 | 131 |
| *2015 dry season* | | | | | |
| Bouaké 189 | 4.5 bcd | 0.50 b | 100 bc | 112 c | 141 ab |
| Bouaké-AM | 4.4 cde | 0.46 d | 104 a | 113 c | 144 ab |
| NIL 130 | 3.8 f | 0.46 cd | 83 e | 98 g | 86 e |
| IR 64 | 4.1 ef | 0.50 bc | 93 d | 101 f | 109 d |
| WITA 9 | 4.7 abc | 0.57 a | 90 d | 106 e | 142 ab |
| Mean | 4.3 | 0.50 | 94 | 106 | 124 |

Notes: Within columns, means followed by the same lowercase letter do not differ significantly by least significant difference (LSD; $P < 0.05$).

**Table 4.** Comparison of paddy yield and grain quality characteristics of WITA 9, Bouaké 189, and IR 64 grown in Bénin and Senegal in 2011 and 2012. Data averaged for each country.

| | Bénin | | | Senegal | | |
|---|---|---|---|---|---|---|
| | Bouaké 189 | IR 64 | WITA 9 | Bouaké 189 | IR 64 | WITA 9 |
| *Milling characteristics* | | | | | | |
| Head-rice yield (%) | 30 | 45 | 30 | 41 | 57 | 41 |
| *Grain appearance* | | | | | | |
| Grain length (mm) | 6.4 | 6.5 | 6.1 | 6.4 | 6.4 | 6.2 |
| Grain width (mm) | 2.2 | 2.2 | 2.1 | 2.1 | 2.0 | 2.1 |
| Length-to-width ratio | 3.0 | 3.0 | 2.9 | 3.0 | 3.2 | 3.0 |
| Chalkiness (%) | 20 | 17 | 19 | 25 | 15 | 28 |
| *Amylose and paste properties determined by Rapid Visco Analyzer* | | | | | | |
| Apparent amylose content (%) | 23 | 22 | 28 | 24 | 24 | 27 |
| Peak viscosity (cP) | 2395 | 2649 | 3323 | 2818 | 2734 | 3426 |
| Breakdown viscosity (cP) | 870 | 1046 | 888 | 1207 | 1217 | 968 |
| Setback viscosity (cP) | 678 | 424 | 1184 | 460 | 331 | 918 |

other varieties, which make it seemingly a good variety for the preparation of popular West African dishes such as *waakye*/*atasa* and *jollof*, for which non-sticky rice is preferred. Although we found some consistent results of grain quality across two different sites, future study should be conducted in Côte d'Ivoire to confirm our findings.

### 3.3. Diseases

There was no significant difference in disease severity among the three BLB isolates tested (data not shown). However, the rice varieties significantly differed for their resistance to the Ivorian isolates (Table 5). NIL 130 was the most BLB-susceptible variety with a disease severity of more than 60%, followed by Bouaké 189. WITA 9 was the most BLB-resistant variety, followed by Bouaké 189-AM, and IR 64, both of which expressed moderate resistance. This resistance of WITA 9 to the BLB isolates tested contradicts observations made in Niger, where the variety was susceptible (Ministère de l'Agriculture, 2012). The difference in pathogenicity of the BLB populations present in the two countries might explain these conflicting results: it cannot be ruled out that isolates with higher pathogenicity exist in Niger. Testing and comparing the pathogenicity of isolates from both countries on differential lines carrying the known *Xa* genes would help answer this question.

There was no significant difference in disease severity of RYMV among the three isolates at 21 and 42 days after inoculation (DAI) (data not shown). Thus, only the means of the three isolates are presented in Table 5. Similarly to a previous study (Oludare et al., 2016), IR 64 (carrying the susceptibility allele *rymv1–1*) was the most susceptible variety in this study. NIL 130, which carries the resistant allele *rymv1–2*, had no symptoms of the virus at either scoring date. This means that this variety was highly resistant to the disease. In contrast, Bouaké-AM, which carries the same allele *rymv1–2* (Bouet & Amancho, 2010), was scored moderately susceptible at 42 DAI. This contrasting result between NIL 130 and Bouaké-AM could be due to differences in their genetic backgrounds and the effects of other alleles. In fact, the gene was introgressed in Bouaké-AM using conventional selection after crossing Bouaké 189 with the *rymv1–2* donor Gigante (Bouet & Amancho, 2010), while its introgression for developing NIL 130 was done using marker-assisted selection (Jaw et al., 2012; Ndjiondiop et al., 2013). The genetic background of NIL 130 is IR 64. Other alleles from Gigante, donor of *rymv1–2*, might have introgressed along with this allele and masked the effect of this allele in Bouaké-AM. WITA 9 was less resistant to RYMV than NIL 130. This confirms previous screening results when this variety was selected in the breeding program (West Africa Rice Development Association (WARDA), 1996) and the statement of the Variety Release Committee of Niger (Ministère de l'Agriculture, 2012) that WITA 9 is resistant to RYMV.

The susceptible and resistant blast checks were also, respectively, susceptible and resistant in this study (data not shown), except for the variety–isolate combination CO 39/BN0119 for which a resistant phenotype was observed (this interaction could be explained by the fact that CO 39 carries resistance gene *Pi-CO39* [Chauhan, Farman, Zhang & Leong, 2002] and isolate BN0119 could not overcome this resistance gene). This therefore suggests that the data collected were satisfactory and could be considered for categorizing the varieties for their phenotypic reaction to blast. The data obtained showed that, apart from the resistant checks, IR 64 had the highest blast resistance level. This result confirmed data recently collected in seven African countries (Bénin, Burkina Faso, Côte d'Ivoire, Madagascar, Mali, Togo, Uganda) (Awande et al., 2016), where this variety was also resistant across all the countries. In fact, IR 64 harbors the resistance genes *Pi20, Pita, Piz-t, Pib, Pik-s, Pi25 (t), Pi27(t), Pi29(t), Pi30(t), Pi31(t), Pi32(t), Pi33(t)*, and *Pir2–3* (Fukuta, Ebron & Kobayashi, 2007; Sallaud et al., 2003) and this pyramiding probably explain its high level of resistance.

**Table 5.** Mean disease scores and resistance status (in parentheses) of Bouaké 189, Bouaké-AM, IR 64, NIL 130, and WITA 9 to selected isolates of bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae), Rice yellow mottle virus* (RYMV), and rice blast tested under controlled conditions in Cotonou, Bénin, November 2016 to June 2017.

| | | | | Rice blast | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bacterial leaf blight (BLB)[1] | *Rice yellow mottle virus* (RYMV)[2] | | Isolates | | | | | | |
| Variety | Mean DS | DS 21 DAI | DS 42 DAI | BN0013 | BN0050 | BN0066 | BN0082 | BN0119 | BN0202 | BN0204 |
| Bouaké 189 | 38 b (MS) | 27 b (MS) | 36 b (MS) | R | R | R | MR | R | MR | MR |
| Bouaké-AM | 24 c (MR) | 21 b (R) | 31 b (MS) | R | R | R | R | R | MS | MR |
| IR 64 | 19 c (MR) | 48 a (S) | 59 a (S) | R | R | R | R | R | R | R |
| NIL 130 | 61 a (S) | 0 c (R) | 0 d (R) | R | R | R | MR | R | MS | MR |
| WITA 9 | 9 c (R) | 8 c (R) | 11 c (MR) | MR | R | R | MR | R | MS | MR |

Notes: [1] Inoculation with BLB isolates ABB1, ABB40, ABB41.
[2] Inoculation with RYMV isolates RBe 10/10, RBe 11/24, RBe 11/41.
DAI, days after inoculation; DS, disease severity.
Within a column, means with the same letters are not significantly different from each other.
Resistance/susceptibility phenotypes for BLB: very resistant (VR) for DS < 1%; resistant (R) for 1 ≤ DS ≤ 12.5%; moderately resistant (MR) for 12.5 < DS ≤ 25.0%; moderately susceptible (MS) for 25.0 < DS ≤ 50.0%; and susceptible (S) for DS > 50%.
Resistance/susceptibility phenotypes for RYMV: resistant (R): 0 ≤ DS ≤ 10.0%; moderately resistant (MR): 10.0 < DS ≤ 25.0%; moderately susceptible (MS) for 25.0 < DS ≤ 40.0%; and susceptible (S) for DS > 40%.
Resistance/susceptibility phenotypes for blast: resistant (R) for DS ≤ 2.0; moderately resistant (MR) for 2.0 < DS ≤ 3.0; moderately susceptible for 3.0 < DS ≤ 4.0; and susceptible (S) for DS > 4.0.

Bouaké 189 had a phenotype comparable to that of IR 64 as it was either moderately resistant or resistant to all isolates. Bouaké-AM (derived from Bouaké 189), NIL 130, and WITA 9 were moderately susceptible to the isolate BN0202 while they resisted the others. The Variety Release Committee of Côte d'Ivoire described WITA 9 as having a good blast resistance level (MINADER (Ministère de l'Agriculture et du Développement Rural), 2002). Based on our results, it can be stated that WITA 9 has an acceptable disease resistance level. The genes controlling its resistance are unknown and further investigations are required to identify them. Moreover, we cannot be sure that this resistance will not fail in some locations in the future.

### 3.4. Adoption of WITA 9 and its impact

This section presents the ex-post adoption rate and determinants as well as the impact of WITA 9 on yield and income. Among the households surveyed in Gagnoa, about 80% of the household heads were male (Table 6). They were on average 47 years old, had six family members, and almost 70% of them had no formal education. Some 90% of the households surveyed had agriculture as their main activity. After the release of WITA 9, some 40% of the households knew of WITA 9, some 34% had access to its seed, and 24% adopted it in 2014. However, the adoption rate among household having knowledge of WITA 9 was 60% and the adoption rate among household having access to WITA 9 seed was much higher (71%). This implies that increasing access to WITA 9 seed would significantly increase its adoption rate. Indeed, the high adoption rate among those with access to WITA 9 seed and the low adoption rate in the whole population indicate a weakness of the rice seed system.

**Table 6.** Selected socio-demographic characteristics of surveyed households in Gagnoa, Côte d'Ivoire, 2014.

| Characteristic | Unit | Value[1] |
|---|---|---|
| Household size | No. (mean) | 6 |
| Age of household head (years) | No. (mean) | 47 |
| Household head with primary education | % | 31 |
| Male household head | % | 80 |
| Household having agriculture as main activity | % | 90 |
| Household had received training in agriculture | % | 14 |
| Household belonging to an association of rice producers | % | 40 |
| Household had knowledge of WITA 9 | % | 40 |
| Household had access to WITA 9 seed | % | 34 |
| Adoption rate of WITA 9 in the whole population | % | 24 |
| Adoption rate among households having knowledge of WITA 9 | % | 60 |
| Adoption rate among households having access to WITA 9 seed | % | 71 |

[1] Sample size = 304.

The determinants of adoption model revealed that there were three main factors that determined WITA 9 adoption status: age of the rice farmer, training in agriculture, and membership of a farmers' association (Table 7). Younger heads of households were more likely to adopt WITA 9 than older household heads. The household heads who had received agricultural training or were members of an association also tended to adopt this variety.

On average, WITA 9 adopters achieved significantly higher yields than non-adopters, with an average yield of 2.3 t ha$^{-1}$ compared with 1.6 t ha$^{-1}$ on average with other varieties (Table 8). The contribution of this variety to yield increase was about 0.738 t ha$^{-1}$ (average treatment effect on treated [ATET] in Table 8) – i.e. current adopters would have produced about 0.738 t ha$^{-1}$ less if they had not adopted WITA 9, and instead cultivated other varieties. Similarly, WITA 9 adopters had higher incomes from rice cultivation than non-adopters (US$ 329 vs. US$ 274 per season). Increased income due to adoption of WITA 9 was about US$ 91 per household per season (ATET in Table 8). When these results were compared with those from a recent metadata analysis for rice in sub-Saharan Africa (Arouna et al., 2017), yield and income gains due to WITA 9 were higher in this study than those from NERICA varieties (including both upland and lowland NERICA varieties) (by 0.32 t ha$^{-1}$ and US$ 58 per household per season) and other improved varieties (by 0.43 t ha$^{-1}$ and US$ 72 per household per season).

### 3.5. Marketability of WITA 9

Some 53% and 60% of consumers who participated in the experimental auctions were male in Gagnoa and Man, respectively. This indicates that in a majority of households, males make the decision on what type of rice is purchased in the two urban markets. Other socio-demographic

**Table 7.** Socio-demographic determinants of adoption of WITA 9 in Gagnoa, Côte d'Ivoire, 2014.

| Determinant | Coefficient | Marginal effects |
|---|---|---|
| Household size | −0.05 (0.03) | – |
| Age of rice farmer | −0.08[a] (0.05) | −0.02* (0.02) |
| Education level | 0.039 (0.02) | – |
| Main activity | 0.26 (0.26) | – |
| Marital status | 0.25 (0.22) | – |
| Agricultural training | 0.9** (0.33) | 0.24* (0.07) |
| Belonging to an association of rice producers | 0.11[a] (0.08) | 0.06* (0.04) |
| Number of observations = 304 | | |
| Wald $\chi^2$ = 54.06 | | |
| Prob > $\chi^2 \leq 0.01$. | | |

Notes: Robust standard errors given in parenthesis.
[a], *, ** denote statistical significance at the 10% ($P < 0.1$), 5% ($P < 0.05$) and 1% ($P < 0.01$) levels, respectively.

**Table 8.** Yield and income in rice cultivation using WITA 9 in Gagnoa, Côte d'Ivoire, 2014.

| | Yield (t ha$^{-1}$) | Income (US$ ha$^{-1}$) |
|---|---|---|
| Mean outcome for adopters | 2.297 (0.38) | 328.5 (51.4) |
| Mean outcome for non-adopters | 1.597 (0.14) | 273.6 (19.2) |
| Difference (naïve method) | 0.700 (0.41) | 54.9 (43.3) |
| Impact (average treatment effect on treated, ATET) | 0.738** (0.20) | 90.9** (46.7) |

Note: Robust standard errors given in parenthesis.
** devotes statistical significance at the 1% level ($P < 0.01$).

characteristics of the shoppers are reported in Table 9. In both urban markets, consumers were willing to pay more for all the alternative rice types (Table 10). In Man, the imported rice 'Uncle Sam' recorded the highest WTP at all stages, and there were only small differences in WTP among local rice types. Our finding in Man is somewhat similar to what has often been observed in West Africa (Demont et al., 2017; Fiamohe, Nakelse, Diagne & Seck, 2015; Naseem, Mhlanga, Diagne, Adegbola & Midingoyi, 2013). In both Gagnoa and Man, aroma, taste, whiteness, cleanliness, and slenderness were most important five selection criteria for consumers; however, the order of the top three (aroma, taste, and whiteness) differed between the two cities (Table 11).

When data from the two urban markets were combined to identify determinants of consumers' revealed price premium for WITA 9 relative to imported rice, change in consumers' WTP for both WITA 9 and imported rice after tasting and group discussion affected the revealed price premium for WITA 9 (Table 12). Consumers who increased WTP for WITA 9 after tasting and group discussion tended to have greater WTP for WITA 9 than for imported rice. In contrast, consumers who increased WTP for imported rice after tasting and group discussion tended to have lower WTP for WITA 9 than for imported rice. Positive relationship between the revealed price premium of WITA 9 and WITA 9 producing area (Gagnoa) indicates that consumers in the WITA 9 producing area (i.e. who were accustomed to it) tended to increase their revealed price premium for WITA 9 relative to imported rice. These findings are consistent with other experimental auctions on rice in West Africa (Demont et al., 2017; Demont, Rutsaert, Ndour & Verbeke, 2013). These results suggest that adoption of word-of-mouth (WOM) communication among poor households and frequent organization of tasting events with them on WITA 9 would improve its sales in the cities. Furthermore, there was a negative relationship between the revealed price premium for WITA 9 and income per capita. This was also the case when the data were analyzed in Gagnoa site alone (data not shown). Poorer consumers tended to prefer to pay more for WITA 9 than for imported rice. WITA 9 might be especially preferred by poor consumers who tend to buy cheap local rice and appreciate upgraded *local* rice. We also found a positive relationship between aroma and the revealed price premium of WITA 9 relative to imported rice: consumers indicating that aroma is an important selection criterion increased their WTP for WITA 9 relative to imported rice. However, WITA 9 is not a fragrant variety. Although we do not know about the actual level of fragrance of the imported rice brands used in this study, they might be fragrant. Further research is needed to better understand what is meant by 'aroma', and its relationship with any varietal traits and pre- and post-harvesting conditions or management. It is possible that WITA 9 was relatively fresher (stored for a shorter time) than imported rice (which requires substantial time for transportation), and this difference could have been reflected in the aroma indicated by consumers. Such understanding could help in the introduction of new varieties, pre-harvest, post-harvest, and processing technologies, as well as knowledge of improved practices that contribute to quality upgrading to meet market demand. Apart from aroma, none of the other important selection criteria in Table 12 were significantly related to the revealed price premium for WITA 9. However, it is noted that no relationship does not mean that these traits are not important, and both imported rice and WITA 9 might have had similarities in these traits. Thus, these intrinsic traits should be considered by breeders in developing new rice varieties, although better understanding of what is meant by 'aroma' and 'good taste' is needed.

**Table 9.** Rice shoppers' socio-demographic characteristics in two urban markets, Gagnoa (2014) and Man (2016) in Côte d'Ivoire.

| Variable | Gagnoa (n = 150) | Man (n = 120) |
|---|---|---|
| Female (%) | 47 | 40 |
| Shoppers having formal education (%)[1] | 81 | 81 |
| Mandé ethnic group (%)[2] | 19 | 18 |
| Age of shoppers (years, average) | 35 | 29 |
| Income per capita (US$, average) | 391 | 637 |
| Household size (average) | 6 | 8 |

Note:
[1] The formal education is a binary variable (did the consumer receive formal education? 1 = yes, 0 = no).
[2] Mandé ethnic group. This ethnic group is the original African rice production group (Olson, 1996; Sharma, 2010).

## 4. Synthesis and conclusions

Due to the social unrest that prevailed in Côte d'Ivoire in the early 2000s and the research and development focus on NERICA varieties within AfricaRice and the international agricultural community during the same period, studies and publications on WITA 9 have been scarce. This is the first study to rigorously evaluate the various attributes of WITA 9. It has confirmed the variety's high yield, resistance to bacterial leaf blight, and tolerance to RYMV and blast. Our impact assessment indicated that this variety can offer

**Table 10.** Descriptive statistics of rice shoppers' willingness to pay (WTP) to upgrade standard to alternative rice types on urban markets in Gagnoa (2014) and Man (2016), Côte d'Ivoire.

| | | Pre-sensory | | | Post-sensory | | | Post-collective | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | WTP (US$ kg$^{-1}$) | | | WTP (US$ kg$^{-1}$) | | | WTP (US$ kg$^{-1}$) | | |
| Urban market, standard rice, and price | Rice upgrade | Mean | SD | *t* test | Mean | SD | *t* test | Mean | SD | *t* test |
| Gagnoa, | WITA 9 | 0.13 | 0.11 | 15.19[a] | 0.13 | 0.11 | 13.90[a] | 0.12 | 0.09 | 15.96[a] |
| Malo Woussou, | Bété rice | 0.07 | 0.07 | 12.68[a] | 0.09 | 0.09 | 11.98[a] | 0.08 | 0.07 | 15.51[a] |
| US$ 0.54 kg$^{-1}$ | Papillon[1] | 0.11 | 0.10 | 13.95[a] | 0.10 | 0.09 | 14.39* | 0.08 | 0.08 | 13.09[a] |
| Man, | Danane | 0.12 | 0.02 | 6.50[a] | 0.12 | 0.02 | 7.27[a] | 0.08 | 0.01 | 9.81[a] |
| Saioua, | Bouaké-AM | 0.10 | 0.01 | 6.99[a] | 0.11 | 0.01 | 8.69[a] | 0.08 | 0.01 | 9.30[a] |
| US$ 0.60 kg$^{-1}$ | WITA 9 | 0.12 | 0.02 | 8.23[a] | 0.14 | 0.02 | 9.34[a] | 0.09 | 0.01 | 10.98[a] |
| | Uncle Sam[1] | 0.21 | 0.02 | 10.64[a] | 0.22 | 0.03 | 7.69[a] | 0.17 | 0.02 | 9.91[a] |

Notes: [1] = imported rice brand.
[a], * Statistical significance at the 10% ($P < 0.1$) and 5% ($P < 0.05$) levels, respectively.

**Table 11.** Proportions of shoppers (%) identifying variables as preferred rice attributes in Gagnoa (2014) and Man (2016), Côte d'Ivoire.

| Variable | Gagnoa | Man | Chi square ($\chi^2$) test |
|---|---|---|---|
| Aroma | 81 | 61 | 13.97** |
| Taste | 72 | 75 | 0.31 |
| Whiteness | 56 | 68 | 3.71[a] |
| Cleanliness | 31 | 51 | 11.33** |
| Slenderness | 28 | 49 | 12.76** |
| Unstickiness | 16 | 18 | 0.11 |
| Head-rice recovery | 0 | 15 | 24.11** |
| Softness | 0 | 15 | 24.11** |
| Swelling capacity | 7 | 13 | 2.67 |
| Other attributes | 3 | 9 | 5.37* |

[a], *, ** denote statistical significance at the 10% ($P < 0.1$), 5% ($P < 0.05$), and 1% ($P < 0.01$) levels, respectively.

**Table 12.** Determinants of shoppers' revealed price premium for WITA 9 relative to imported rice in Gagnoa (2014) and Man (2016) urban markets in Côte d'Ivoire.

| Variable | Coefficient |
|---|---|
| Taste premium for WITA 9 | 33.11 (9.44)** |
| Taste premium for imported rice | −23.47 (6.30)** |
| Word-of-mouth (WOM) premium for WITA 9 | 31.77 (7.91)** |
| WOM premium for imported rice | −28.55 (6.26)** |
| Mandé (1 = yes; 0 = no) | 2.04 (2.12) |
| Female (1 = yes; 0 = no) | 1.89 (1.98) |
| Formal education (1 = yes; 0 = no) | −0.37 (2.43) |
| Age | 0.04 (0.10) |
| Income per capita (US$ 1000) | −1.86 (0.81)* |
| (Taste premium)/(Income per capita) | −99.99 (222.73) |
| (WOM premium)/(Income per capita) | 136.83 (1363.38) |
| Household size | −0.46 (0.11) |
| WITA 9 producing area (1 = Gagnoa; 0 = Man) | 4.86 (1.80)** |
| Cleanliness | −0.45 (1.78) |
| Whiteness | 1.97 (1.71) |
| Head-rice recovery | −1.35 (1.62) |
| Slenderness | −0.29 (1.83) |
| Unstickness | 1.66 (2.00) |
| Taste | 0.56 (1.80) |
| Aroma | 3.27 (1.95)[a] |
| Softness | −0.10 (1.57) |
| Swelling capacity | −1.53 (2.74) |
| Other attributes | −1.48 (2.42) |
| Constant | −4.61 (6.27) |
| No. of observations | 261 |
| $F(23, 237)$ | 2.95** |
| $R^2$ | 0.27 |

Notes: Robust standard errors are given in parenthesis.
[a], *, ** devote statistical significance at the 10% ($P < 0.1$), 5% ($P < 0.05$), and 1% ($P < 0.01$) levels, respectively.

opportunities for enhancing productivity and rice import substitution in Côte d'Ivoire. This study also indicated that there is a good market opportunity for WITA 9, especially in Gagnoa where it is extensively grown. Thus, WITA 9 can be considered as an ideal innovation for enhancing productivity and reducing rice imports in Côte d'Ivoire. Although higher yield and income gains from adoption of WITA 9 in comparison with NERICA and other improved varieties were observed, adoption rate was still low in Côte d'Ivoire. It is noted that WITA 9 is not that popular in sub-Saharan Africa, except in Côte d'Ivoire. It was released in Niger, but – partly due to the poor seed system of the country – was not successfully diffused on a large scale (Mounirou Sow, personal communication, 22 December 2016). In Guinea, seed of this variety has been disseminated by several projects along with NERICA varieties. However, lowland NERICA varieties have been strongly promoted in comparison with WITA 9. Consequently, this variety did not become popular in Guinea. Therefore, an effective seed delivery system and enhancing farmers' and consumers' awareness of this variety would be key for accelerating the impact of this variety not only in Côte d'Ivoire but also in other West African countries.

One weakness of this paper is that our studies were conducted in different locations including other countries in West Africa. As mentioned above, we had difficulty conducting detailed trials in Côte d'Ivoire due to social unrest. This is the main reason why different studies were conducted in different locations. In the future, when any similar type of assessment is conducted, we highly recommend conducting studies in the same target locations.

Although the impact study confirmed the results of agronomic performance of WITA 9 obtained in field experiments in this study, there was a large difference between yield in field experiments and average yield obtained in farmers' fields. The difference was up to 4 t ha$^{-1}$. The difference could be attributed to crop management including nutrient management practices. Although we do not have data on farmers' fertilizer application rate in this impact study, it has been reported that farmers' fertilizer application rate for rice in Gagnoa is generally low (Niang et al., 2017; Saito et al., 2017). Thus, not only introducing rice varieties but also introducing good agricultural practices is essential for enhanced rice yield in this study area.

Laboratory analysis in this study (Table 4) indicated that WITA 9 is not likely to have either softness or stickiness. Those attributes are not likely to be important for consumers in Côte d'Ivoire. Thus, these attributes might not be important criteria for breeding. Among the five most important selection criteria for consumers (aroma, taste, whiteness, cleanliness, and slenderness), better understanding of what is meant by 'aroma' and 'good taste' is needed, and these should be able to be determined in further lab analyses. Slenderness could be easily determined by length-to-width ratio shown in Table 4 and WITA 9 can be considered as slender type. This is an intrinsic attribute and is less affected by environment and management practices. Chalkiness might be related to whiteness and cleanliness among the five important criteria. As WITA 9 did not have a good score for chalkiness (Table 4), this could be improved through breeding for quality upgrading to meet consumers' demand.

Recently, AfricaRice and its partners have named best-performing breeding materials 'Advanced Rice for Africa' (ARICA) based on results from multi-locational trials within the framework of the Africa-wide Rice Breeding Task Force (Africa Rice Center [AfricaRice], 2014). However, there is currently limited information on these varieties in the public domain, except for yield performance and resistance to abiotic stresses (AfricaRice, 2014). Comprehensive assessment of rice varieties that are newly developed and promoted should be considered to make sure that they can have a significant impact on farmers' livelihoods and competitiveness against imported rice before initiating large-scale seed production and dissemination.

## Note

1. 'WITA' is a contraction of WARDA and IITA.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

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