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Cord

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Coconut Research & Development, Vol. 38, 2022

Table of Contents

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Coconut Research & Development, 2022, 38: 1-5

In Vitro Study on Actinomycetes Extracts Against the Stem Bleeding Disease of Coconut

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Abstract

Several compounds produced by Actinomycetes group of bacteria have proven potential in inhibiting plant pathogenic fungi. In the present study, two microbial ethyl acetate extracts from Streptomyces were tested for their antifungal properties against *Thielaviopsis paradoxa*, the causal organism of stem bleeding disease in coconut. The cultural filtrates of 2 strains of Streptomyces (AFL-1 and AFL-2) were extracted with Ethyl acetrate. The resulting ethyl acetate extract of AFL-1 showed complete *in-vitro* inhibition of fungal growth at relatively low concentrations (0.25%) while Ethyl ecetate extract of AFL-2 needed higher concentrations (over 0.5%) to eliminate pathogen growth. This finding indicate their potential and further exploitation as biopesticides for the control of deadly pathogen
T. paradoxa.

Keywords: antifungal effects, coconut, phytopathogen, streptomyces extracts, stem bleeding, *Thielaviopsis paradoxa*

Introduction

Thielaviopsis paradoxa (de Seyness) Von Hohnel, is a soilborne plant pathogen that causes diseases in diverse economically important crop plants. Stem bleeding disease of coconut caused by *Thielaviopsis paradoxa* mainly infects wounds and openings in the coconut stem. However, the fungus can infect multiple parts of a palm and therefore cause several infection points. As decay progresses, a dark pigmented liquid bleeds down the trunk from the point of invasion covering the stem surface with a superficial black layer of stem fluids. The sap flow may extend several feet down the trunk, blackening the trunk as it dries. In advanced cases, the interior of affected trunks becomes hollow due to the decay of internal tissues. Severely affected or untreated palms may rot out completely inside and die. Basal stem invasion may occur in wet areas, producing a black collar of diseased-stem tissue at the plant-soil interface. Roots may also show blackening and decay.

The disease is prevalent in all soil types in tropical coconut growing regions. In Karnataka the disease was reported as a serious concern, while infestation turned out rampant in Appangala (Coorg district, Karnataka State) and Vittal (Karnataka State). Copius gushing of brown liquid was noticed on palms at Appangala, the coolest among the places. The gummy exudates contained conidia of *T. paradoxa*. The disease was equally distributed in all tall, dwarf and hybrid varieties (Rajesh Muthu, et al., 2013). The disease is most common where wounds occur to palm stems in highly irrigated or moist landscapes. The wounds exposed to infested soil are prone to infection. The pathogen can spread from soil to open wounds by splashing rain or irrigation water. Growth cracks on the coconut trunk, severe downpours, water stagnation, imbalances in nutrition, excess salinity, and plant stress can act as predisposing and aggravating factors.

Control of *T. paradoxa* is achieved by cultural practices and chemical treatment with triadimefon. However, it is desirable to integrate biological control agents into disease management plans to minimize the environmental impact of agrochemicals (Sánchez, et al., 2007).

In recent years, compounds from different microbial groups have been described as having antifungal activity, among others are the Actinomycetes group and their constituent (Kekuda, et al., 2015) A wide range of species have been explored for their secondary metabolites in the past few decades. Secondary metabolites are complex volatile compounds synthesized naturally during the process of secondary metabolism (Hayakawa, et al., 2004).

The metabolites produced are generally a high molecular weight group of compounds, which directly acts as antifungal agents or have structural biopolymers which have localized action especially at the sites of infection which restricts fungal development in plants either through the formation of lignin, cellulose and other such kinds of structures (Gebreyohannes, et al., 2013). These compounds may be active by themselves or by the production of enzymes like peroxidases which are antifungal (Harman, 2000). In general, the interest in such antifungal compounds depends upon the concentration required for activity and the biological spectrum of activity (Peela & Porana, 2016). The presence of different types of aldehydes, phenolics, terpenes, and other antimicrobial compounds justifies that these compounds are effective against a diverse range of plant pathogens (Goodfellow et al., 2012 and Crawford et al., 1993). Today technology has evolved many folds and different chemical/synthetic products are available in the market to deal with fungal plant pathogens. But instances of chemical residues in soil and plant produce posing serious health and environmental hazard has again jeopardized the use of chemical methods to control infections caused by notorious plant pathogens. Understanding the need of the hour, many research has studied and indicated the potential of different naturally available compounds which can be harnessed from a wide range of microbial diversity present around us.

The objective of this study was to examine the antifungal activity solvent extracts of two strains of Actinomycetes derived through a microbial fermentation process.

Materials and Methods

Sample collection

Ten soil samples were collected from the foot of Nandi Hill region of Bangalore Rural, Karnataka, India. The samples were collected from 5-25 cm depth by sterile method from four locations in Nandi Hills area and transported aseptically to the microbiology laboratory of Agferm Innovations Private Limited, Bangalore. The pathogen *T. paradoxa* was collected from tissues of stem bleeding infected palms in Hassan district.

Isolation of pathogen

Infested stem portion where bleeding symptoms were conspicuous was chiseled out carefully. This was surface sterilized with 0.1% sodium hypochlorite followed by 3 washes in sterilized distilled water (SDW). The stem bits were plated on Potato Dextrose Agar (PDA) media plates under aseptic condition. The plates were incubated for three days at 29 + 1°C and observed for any growth.

The incubated plated showed black pigmentation with profuse mycelial growth and high degree of sporulation. Microscopic observation confirmed to the characteritics of *T. paradoxa*, the conidiophores were straight, hyaline to pale brown, up to 200 µm long, with a terminal conidia-bearing cells in chains. The conidia were cylindrical with square ends, hyaline to pale brown, 7-12 × 3-5 µm. The chlamydospores were borne terminally in chains from short hyphal branches with pale brown to brownish-black, smooth, oval and 10-20 × 5-10 µm.

Isolation of Actinomycetes

Calcium carbonate enrichment methods were used to isolate Actinomycetes. The soil samples were mixed with $CaCO_3$ at the ratio of 10:1 and were incubated under moisture-rich conditions for seven days at room temperature (Hayakawa et al., 2004). The soil was further held in a water bath at 50°C to destroy other vegetative microorganisms. Isolation and enumeration of Actinomycetes were performed by the soil dilution plate technique using starch case, in agar medium (g/l: Starch 10 gr, Casein 0.3 gr, KNO_3 2 gr, NaCl 2 gr, K_2HPO_4 2 gr, $MgSO_4.7H_2O$ 0.05 gr, $CaCo_3$ 0.02 gr, $FeSO_4.7H_2O$ 0.01 gr, and Agar 18 gr). To minimize the fungal and bacterial growth, actdione 20 mg/L, and nalidixic acid 100 mg/L were added. The plates were incubated at 30°C for 10 days. After the incubation period, plates were examined for the presence of Actinomycetes colonies. The colonies likely to be the fungus

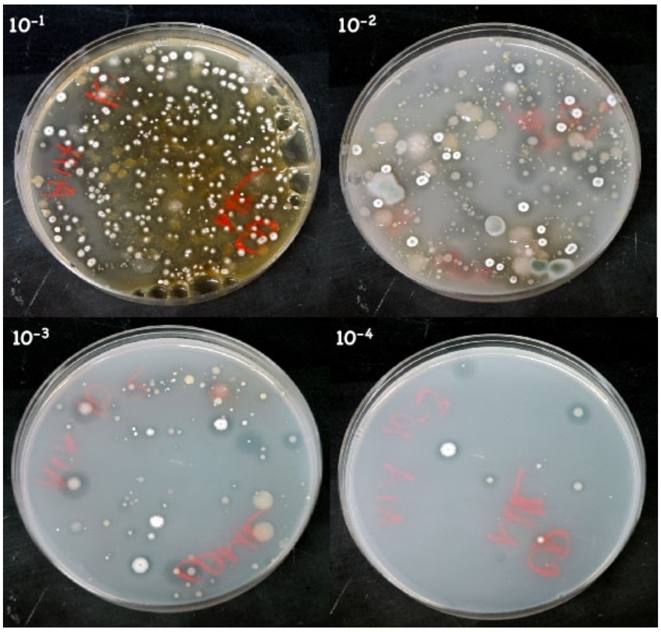

Figure 1. Plate 1, showing Dilution plates up to 10-4 colonies of Actinomycetes on SCA media

were picked up and purified on media and incubated at room temperature for about 7 days (Plate 1).

Characterization of the Isolates

Morphological, physiological, and biochemical characterization of Actinomycetes

Identification of Actinomycetes to genus level was conducted by first using morphological and chemical criteria according to Bergey's Manual of Determinative Bacteriology (Goodfellow et al., 2012 and Crawford et al., 1993). Cultural characteristics of the isolates were studied based on the intensity of the growth, growth pattern, colony color along with the color of aerial mycelia on Tryptone yeast agar (ISP Medium 1), yeast extract malt extract agar (ISP Medium 2), Oatmeal agar (ISP Medium 3), Inorganic salt starch agar (ISP Medium 4), Glycerol Asparginine agar (ISP Medium 5), Peptone yeast extract iron agar (ISP Medium 6), Tyrosine agar (ISP Medium 7) as described by Shirling and Gottlieb (1966) and also on Starch casein agar, Potato Dextrose agar, Kuster's agar and CzapekDox agar. Gram staining and spore surface morphology was examined by scanning electron microscopy (SEM). The arrangement of spore and sporulating structures were examined microscopically by using the coverslip culture method (Mitchell & Britt, 1981). The mycelium structure, color and arrangement of conidiophores and arthrospore on the mycelium were observed through the oil immersion (1000×) microscope (Plate 2).

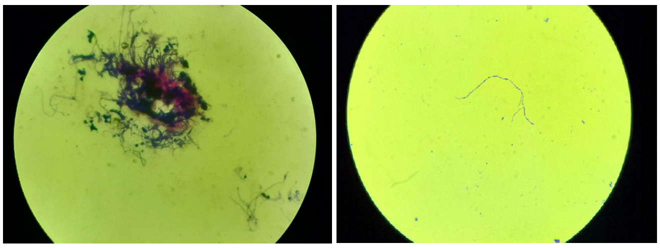

Figure 2. Image of Streptomyces species on Gram staining in Oil immersion microscopy

Biochemical characterization of Actinomycetes

The isolates were inoculated into an ISP-2 medium M1 medium. Incubation of the slide was done at 37°C for 7 days. Staining with methylene blue was done followed by observation of the slides under the microscope after staining with methylene blue stain (Plate 3). Based on physical parameters two isolates were selected and were studied further.

Diagnostic tests of Actinomycetes strains were performed based on macro and microscopic features according to Bergey's Manual of Systematic Bacteriology (Goodfellow et al., 2012 and Crawford et al., 1993). The genus of two selected Actinomycetes was ascertained using the above methods and were found to be of genus Streptomyces. These suspected pure Actinomycetes cultures (AFL-1 and AFL-2) were inoculated

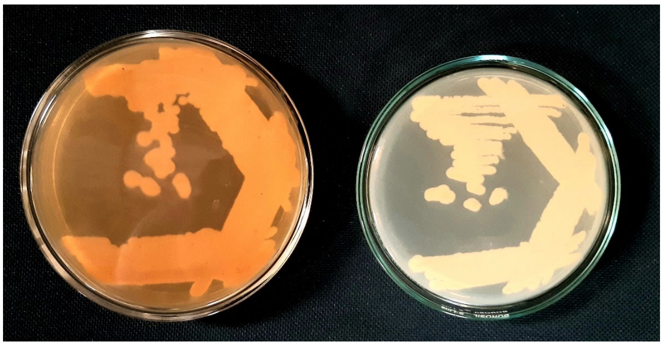

Figure 3. Streptomyces growth on Actinomycetes agar

on ISP-2 slants and after the incubation period, the slants were taken for antifungal screening. The stock culture was preserved in 50% glycerol.

Fermentation and extraction of secondary metabolite

Spores (107/ml) of the two isolates were used to inoculate 1,000 ml Erlenmeyer flasks containing 200 ml of Actinomycetes media each. After six days of incubation at 30°C in an orbital incubator shaker at 200 rpm the flask was opened, and Ethyl Acetate was added to the broth in the ratio of 1:1 and was again shaken for 24 hrs. This whole solution was evaporated at 50°C in a rotary vacuum evaporator to eliminate the solvent fully and concentrate the extracted metabolite broth up to 10 folds. A final volume of 20 ml of secondary metabolite concentrate was retrieved and was tested against *T. paradoxa*.

Fungal growth inhibition test/poisoned food technique

To determine the effect of different concentrations of the two microbial extracts on the growth of fungus it was diluted with acetone in a 1:1 ratio and was added into potato dextrose agar media at 0.1, 0.25, 0.5, 0.75, 1, 2.5, and 5% concentration. Treated media (20 ml) was then poured into the petri plates and allowed to solidify. Mycelial plugs (3 mm in diameter) of pure culture of *T. paradoxa* were placed in the center of each PDA plate (9 cm diameter). All the experimental transfers were performed aseptically under a laminar airflow cabinet. These plates inoculated with fungus were incubated at 28°C and 70% RH for 5-7 days. Mycelial growth was measured every day until plates were completely colonized with mycelium. Plates with only culture media and with extracts were also placed with *T. paradoxa* mycelial plugs and used as control. A solvent control was also set up with media and solvent. The experiments were done in triplicates.

Statistical analysis

All statistical analyses were carried out using Analysis of Variance (ANOVA). ANOVA was performed on all experimental data and means were compared using Duncan's multirange test. The significance level was $p<0.05$.

Table 1. Growth (mean ± SD) of *T. paradoxa* mycelium in different concentrations of results of Extract 1

Conc. of media in %	Colony Diameter (cm)			
	After 1 day	After 3 days	After 5 days	After 6 days
0.1	1 ± 0b	1.2 ± 0.1b	2.8 ± 0.11b	3.17 ± 0.15b
0.25	0 ± 0a	0 ± 0a	0 ± 0a	0 ± 0a
0.50	0 ± 0a	0 ± 0a	0 ± 0a	0 ± 0a
0.75	0 ± 0a	0 ± 0a	0 ± 0a	0 ± 0a
1.00	0 ± 0a	0 ± 0a	0 ± 0a	0 ± 0a
2.50	0 ± 0a	0 ± 0a	0 ± 0a	0 ± 0a
5.00	0 ± 0a	0 ± 0a	0 ± 0a	0 ± 0a
Control	1.7 ± 0.34c	2.88 ± 0.4c	4.2 ± 0.12d	7.03 ± 0.15d
Solvent	1.78 ± 0.2b	2.79 ± 0.12c	3.73 ± 0.25c	6.57 ± 0.15d

Table 2. Growth (mean ± SD) of *T. paradoxa* mycelium in different concentrations of Extract 2

Conc. of media in %	Colony Diameter (cm)			
	After 1 day	After 3 days	After 5 days	After 6 days
0.1	3.07 ± 0.12c	3.87 ± 0.16c	4.23 ± 0.25b	6.30 ± 0.4b
0.25	2.87 ± 0.19b	3.23 ± 0.22b	3.93 ± 0.3b	6.50 ± 0.1b
0.50	2.50 ± 0.10b	3.16 ± 0.08b	4.10 ± 0.1b	6.30 ± 0.1b
0.75	0 ± 0a	0 ± 0a	0 ± 0a	0 ± 0a
1.00	0 ± 0a	0 ± 0a	0 ± 0a	0 ± 0a
2.50	0 ± 0a	0 ± 0a	0 ± 0a	0 ± 0a
5.00	0 ± 0a	0 ± 0a	0 ± 0a	0 ± 0a
Control	2.83 ± 0.13c	3.80 ± 0.15b	4.70 ± 0.1d	7.10 ± 0.15d
Solvent	2.33 ± 0.12b	3.50 ± 0.15b	4.23 ± 0.1d	6.50 ± 0.25c

Results and Discussion

Diagnostic tests of different isolates of Actinomycetes strains were performed based on macro and microscopic features according to Bergey's Manual of Systematic Bacteriology. The genus of two selected Actinomycetes (AFL-1 and AFL-2) was ascertained and found to be of genus Streptomyces. The two strains were morphologically different in terms of pigmentation. AFL-1 showed pinkish pigmentation on agar plate with irregular and serrated edges characteristics. While the other isolate AFL-2 exhibited no such pigmentation on agar plate. The pigmentation is highly coorelated to the presence of various potent bio active agents.

Biochemical characteristics, Mycelia color phenotypes and sugars utilization were highly similar in both the strains isolated. When compared to AFL-2 strain the appearance of substrate mycelia of AFL-1 was pinkish. Indole production was noted in the AFL-2. Most of the sugars tested as carbon source were commonly used by both the strains. Differences were situated in the case of xylose which was used by the strain1 but not by AFL-2. In addition, AFL-1 were able to use mannose, glycerol galactose; sugars with no indication found for the AFL-2.

In the present study the two Streptomyces strain AFL-1 and AFL-2 active against *T. paradoxa* was evaluated. The level of inhibition of pathogen and the toxin produced were strain specific. Streptomyces strain produces several bio control agents/compounds which inhibit spore germination of variety of fungal pathogens. The cultural filtrate of AFL-2 were extracted with ethyal acetate. The resulting crude extractexhibited antifungal property against *T. paradoxa*. The results of the antifungal tests showed that AFL-1 extracted with ethyl acetate showed high inhibition rate at lower concenteration compared to AFL-2 extract. The effects of AFL-1 and AFL-2 are shown in Tables 1 and 2 respectively.

AFL-1 was found to be the most effective in inhibiting fungal growth. All the concentrations, except 0.1% were effective in controlling the growth of the fungal pathogen (Table 1).

AFL-2 was not effective when compared to AFL-1 in inhibiting fungal growth. Specifically, at lower concentrations, the inhibition was almost nil (Table 2).

The growth of pathogen was not restricted completely with AFL-2 at lower concentrations of 0.1 – 0.5%. The pathogen grew in both control and solvent treated.

In this study, 2 different extracts of Actinomycetes sp. were investigated against phytopathogenic fungus *Thielaviopsis paradoxa*. Growth inhibition studies indicated that AFL-2 was found to be the most potent against the fungus. They completely inhibited the growth of fungus in all the concentrations tested. These may be further tested in field conditions and formulated to be used as an environmentally safe alternative to chemical fungicides.

Conclusion

Secondary metabolites through microbial derivation serves as an important source for plant disease management. From the study, it can be concluded that the two streptomyces strains isolated, harbours many important volatile secondary metabolites that can inhibit spore germination of *T. paradoxa* at various degrees of infection. The level of inhibition of pathogen and toxin produced were strain-specific. AFL-1 strain could be an important sources of new compounds or analogues with possible interesting use as fungicide. The comparison between different streptomyces strains in terms of their metabolite production showed consistent differences. Thus, there seems to be constitutive metabolites responsible for the difference in efficacy on plant pathogen *T. paradoxa*, this could be further exploited for commercialization and more field evaluation.

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Estimating Technical Efficiency and its Determinants in the Coconut Plantations: The Case of Kurunegala Plantations Limited, Sri Lanka

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Abstract

This study estimated the Technical Efficiency (TE) of coconut production in Sri Lanka using the stochastic frontier production function procedure. Data on inputs and coconut production recorded by Kurunegala Plantations Limited from 2000 – 2018 were used for the analysis. The stochastic production frontier in Cobb-Douglas form and the inefficiency model were estimated by single-step Maximum Likelihood method using STATA 14 computer software package treating coconut yield as the dependent variable and fertilizer, rainfall, labor, chemicals, tractor hours, mulching harrowing/plowing, agro-ecological zones, education level of the managers and bearing coconut extent as independent variables. Results revealed that TE of coconut production ranged from 81-98%, with an average of 88%, indicating that there is scope for increasing the production by as much as 12% without increasing inputs and simply using a higher technology level. The outcome of the analysis shows that inorganic fertilizer, rainfall, labor, tractor hours, and mulching are kind positive and significant. In contrast, agro-chemicals such as weedicides, fungicides and pesticides and plowing/harrowing did not show a significant contribution to coconut production. In respect of the farm and farmer-specific characteristics, the size of the estate has a positive relationship with technical inefficiency, meaning that smaller estates are more efficient than larger estates. It also shows that the agro-ecological zones and educational level have no significant effect on the efficiency of coconut production. The results highlight the need for government and private sector assistance in improving the efficiency of smallholders and promoting access to productive inputs.

Keywords: coconut plantations, stochastic frontier, technical efficiency, fertilizer response in coconut

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Introduction

Coconut, one of the major plantation crops in Sri Lanka, plays a vital role in sustaining the national economy, food security, and people's livelihood. Coconut cultivation occupies 20% of the total agricultural land in the country (DCS, 2014) while contributing to GDP and export earnings around 0.7% and 5.1%, respectively (CBSL, 2019). This sector employs around 135,000 people in production and industry and provides a livelihood for 698,168 smallholders (DCS, 2012). The annual average coconut production is about 2,800–3,000 million nuts, of which approximately 70% is utilized for domestic culinary purposes and the balance is divided among value-added coconut-based processing industries (CDA, 2019). Over the years, the country's coconut production remains stagnant while the demand for coconut for culinary nuts and industrial use is increasing. Coconut supply has been uncertain due to many reasons such as the impact of climate change, price fluctuation, high cost of production, pests and diseases, fragmentation of coconut lands, scarcity of labor, etc. Limitation of increasing of coconut supply is attributed by availability and opportunity cost of suitable land for the cultivation, a constraint of capital, declining production of old senile coconut palms. Since, there is a limited scope to increase the coconut supply either by expanding the area under the coconut or increasing the use of costly inputs such as labor and fertilizer, exploring the ways and means to obtain the maximum gains from the more efficient use of existing technology with given inputs is justified.

Coconut is grown under various agro-ecological zones and other characteristics such as availability of inputs and different management practices. Therefore, the performance of these production units is diverse. There are various measures to assess the performance of a production unit, and among them, productive efficiency is an important measurement of producer performance. Technical efficiency (TE) measurement is one of the most commonly used methods for measuring the production performance of an economic unit. The TE determines the level of efficiency of an economic unit which will enable the identification of the factors by which improvements can be made while providing useful information for policy formulation. Since there is little empirical evidence of the technical efficiency of coconut production, it necessitates an analysis of the production efficiency of the major coconut producers to determine the magnitude of gains arising from minimizing inefficiencies while helping in formulating policy measures to reduce the production constraints. Hence, the objectives of this study were to estimate the technical efficiency by using stochastic frontier analysis (SFA) of coconut production, identify the key determinants of inefficiency, and rank the estates according to the TE.

Methodology

Technical efficiency in crop production can be defined as a farmer's ability to maximize outputs under a given set of inputs and technology (Mango, et al., 2015). The degree of technical inefficiency reflects an individual farmer's failure to attain the highest possible output level given the set of inputs and technology used. The highest possible output, using available input and technology, is represented by the production frontier. The distinction between technological change and technical efficiency is important. The technological change reflects a shift of the production frontier, as new technologies enable output per unit of input to increase (Bravo-Ureta, 2007). Technical efficiency, on the other hand, explains the difference between potential and observed yield for a given level of technology and inputs.

Theoretical framework

Theoretically, the productive efficiency of a firm consists of two components: technical efficiency, which reflects the ability of a firm to obtain maximal output from a given set of inputs, and allocative efficiency, which reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices. These two measures are then combined to measure total economic efficiency or productive efficiency (Farrell, 1957). These measures can be input or output orientation. Later, this has been evolved to develop a stochastic frontier approach for parametric function such as Cobb-Douglas form or non-parametric piecewise-linear technology and evolved to Data Envelopment Analysis (DEA) approach. The estimation of frontier function and efficiency can be completed either in one stage or in two stages. The two-stage analysis of explaining the level of technical efficiency (or inefficiency) was criticized by Battese and Coelli (1995) as being contradictory in the assumption made in the separate stages of analysis. This study follows the Battese and Coelli (1992) approach of modeling both the stochastic and technical inefficiency effect in the frontier using maximum likelihood in a single-step analysis in Cobb-Douglas form to assess the stochastic production frontier of coconut production at the estates level.

The stochastic frontier models introduce a disturbance term representing statistical noise, measurement error, and exogenous shocks beyond the control of the production unit, which would otherwise be attributed to technical inefficiency and provides the basis for conducting statistical tests of hypothesis regarding the production structure and the degree of inefficiency. This model is composed of an error structure comprising a two-sided symmetric term and a one-sided component. The two-sided error captures random effects outside the control of the plantations, including the weather conditions, measurement errors, or other random disturbances typical of empirical data, while the one-sided non-negative component reflects the technical inefficiency. The stochastic production frontier model was specified as:

$$y_i = (x_i; \beta)\exp f(v_i - u_i),\ i = 1, 2, \ldots, N \quad (1)$$

Where y_i denotes the output of single farm i, $f(.)$ is the production frontier, x_i represents a vector of the inputs used on the i^{th} farm, is a vector of unknown coefficients to be estimated, v_i is the two-sided error and u_i is the one-sided error representing technical inefficiency (TIE). The two-sided error v_i is assumed to be independently and identically distributed as N $(0,\sigma_v^2)$, while u_i is assumed to have a half-normal distribution, i.e. a non-negative truncation of the N (o,σ^2) distribution. The outputs can either be measured as quantities for a single crop or more than one crop. The measure of technical efficiency (TE) relative to the production frontier are defined as:

TE = Y_i / Y_i^*, where $y_i^* = f(x_i, \beta)$ highest predicted value for the i^{th} firm

The TE of the production for the i^{th} farm was defined as the ratio of observed production to the maximum feasible production as the following equation:

$$\text{TEi} = \frac{f(x_i; \beta)\exp(v_i - u_i)}{f(x_i; \beta)\exp(v_i)} = \exp(-u_i) \quad (2)$$

Battese and Coelli (1988) suggest that TE should be predicted using its conditional expectation, given the composed random error, v_i-u_i, evaluated at the maximum-likelihood estimates of the equation (2). In the case of a production frontier, TE_i will be valued between zero and one, therefore,

Technical inefficiency = 1 - TE_i

According to Battese and Corra (1977), the variance ratio parameter γ, which is related

to the $\gamma = \sigma^2_u / \sigma^2$

where, $\sigma^2 = \sigma^2_u + \sigma^2_v$

So that $0 \leq \gamma \leq 1$

When γ is close to 0, the difference between yield and efficient yield is entirely due to statistical noise. On the other hand, if the γ is close to 1, the difference is attributed to the growers' less efficient use of the technology.

To estimate the factors that contribute to TIE, we applied the model which was proposed by Battese and Coelli (1995), specified as:

$$TIE_i = Z_{i\delta} + \omega_i \tag{3}$$

Where z is a (1×M) vector of explanatory variables affecting TIE, δ is an (M×1) vector of coefficients to be estimated, and ω_i are unobservable random errors defined by the truncation of the normal distribution.

$$N\ (0, \sigma^2), \text{ such as that } w_{i \geq -Zi}\ \delta \tag{4}$$

In this study, we use the panel data. Pitt and Lee (1981) specified a panel data version of the Aigner, Lovell and Schmidi (1977) half –normal model as follows:

$$\ln y_{it} = f(x_{it}; \beta) + v_{it} + u_{it} \ \ \| \ \ i = 1.,2,\ldots N,\ t = 1,2\ldots..T \tag{5}$$

Where $f(.)$ denotes a suitable functional form, in this study we use Cobb-Douglas functional form using maximum likelihood estimation (ML).

Empirical model

The stochastic production frontier in Cobb-Douglas form and the inefficiency model were estimated by single-step Maximum Likelihood method using STATA 14 computer software package treating coconut yield as the dependent variable and fertilizer, rainfall, labor, chemicals, tractor hours, mulching harrowing/plowing as independent variables in the stochastic frontier model while agro-ecological zones, education level of the managers and bearing coconut extent as independent variables in the inefficiency model. The empirical models for both the stochastic frontier model and the inefficiency model are stated in equations 6 and 7. A range of factors, including estate level characteristics and socio-economic, environmental, and non-physical, are likely to affect the efficiency of coconut growers. According to past studies, the responsiveness of coconut production to some inputs such as fertilizer and rainfall has proven the presence of lag effects. Therefore, two years lag for fertilizer (De Silva, 1972) and one-year lag for the rainfall were used in the model where it is necessary to represent the characteristic nature of the coconut cultivation.

$$Ln\ Y_i = \beta_0 + \beta_1 \ln LBO + \beta_2 \ln FER_{t-2} + \beta_3 \ln CHE + \beta_4 \ln RF_{t-1} + \beta_5 \ln MAC + \beta_6 \ln MUL + \beta_7 \ln PUL + v_i + u_i \tag{6}$$

Where,
Yi = Annual coconut production (Nuts/year)
LBO = Labor (Man days)
FER = Fertilizer (Kg)
CHE =Agro chemicals (Liters)
RF = Annual rainfall (mm)
MAC = Machinery usage (Tractor hours)
MUL = Mulching base on the coconut trees (Number of the coconut trees)
PUL = Ploughing /harrowing (Hectares)
β_0 - β_7 = Coefficients to be estimated
v_i = Independently and identically distributed random errors
u_i = Non-negative random variables which are independently and identically distributed

In the inefficiency model; equation 7, non-negative error U_{it} is expressed as a function of the agro-ecological zone, educational qualifications of the management, and the bearing coconut extent. W_{it} is an unobservable random error.

$$U_{it} = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + W_{it} \tag{7}$$

Where,
U_{it} = Non-negative random variables
Z_1 = Agro-ecological zones (1 for wet zone and 0 for intermediate zone)
Z_2 = Educational levels of the management (1 for basic 0 for diploma-level and above)
Z_3 = Bearing coconut extent (ha)
δ_0 - δ_3 = Coefficients to be estimated
W_{it} = Unobservable random variables

The coefficients of the variables for both stochastic production frontier and technical inefficiency models were estimated by one step Maximum Likelihood (ML), time-invariant, fixed effect, output-oriented model using the computer program STATA.

Data collection and analysis

Secondary panel data available in nine area estates belonging to Kurunegala Plantations Ltd. over nineteen years from 2000-2018 were used for the analysis. The estates are Attanagalla, Dambadeniya, Dodangaslanda, Hiriyala/Wariyapola, Dhathusenapura, Katugampola, Mahayaya, Narammala and Kurunegala. These estates are situated in Kurunegala and Gampaha districts that cover the major coconut growing area of Sri Lanka. The company has maintained records of input used, output, and other management practices.

Results and Discussion

Descriptive statistics of the sample

The summary statistics of the variables used in the stochastic frontier model and inefficiency model are presented in Table 1. In terms of socio-economic characteristics, since the Kurunegala Plantations Limited (KPL) is a fully government-owned plantation management company, a lot of guidelines have been issued for the management of the estates; thereby, farmer-specific characteristics are controlled. However, the bearing coconut extent and two dummy variables, namely agro-ecological zones, and the management's education levels were considered to analyze the inefficiency model. In the agro-ecological zones, the majority of the sample, 68%, belongs to the Intermediate Zone while 32% belongs to the Wet Zone. Among the managers of the estates, while 62% have basic educational qualifications 38% have obtained higher educational qualifications (Diploma and above).

Results of the stochastic frontier model

Table 2 shows the maximum likelihood estimates of the stochastic frontier production function model and inefficiency model with the determinants of the technical efficiency defined by equations 6 and 7. As shown in Table 2, the estimate of γ is 0.59, which indicates that only 59% of the total variation in coconut output was due to technical inefficiency. Therefore, the difference between coconut yield and efficient yield in the KPL is mainly due to technical inefficiency. This value is lower than the values recorded by Mangika et al. (2009) and Selvam et al. (2018). They have recorded an estimate of 0.85 and 0.84 for γ in a study conducted for assessing the technical efficiency of smallholder coconut growers in Sri Lanka and the Coimbatore District in India, respectively. However, in both studies, the focus was on smallholder coconut growers.
The ML estimates of inorganic fertilizer, rainfall, labor, tractor hours, and mulching are positive and significant at 1% significant level. The estimated ML coefficients of agrochemicals and plowing/harrowing did not show a significant contribution to coconut production. The positive significant coefficient of inorganic fertilizer application of 0.16 indicates that a one-unit increment of fertilizer application will increase coconut output by 0.16. This finding is in line with Selvam et al. (2018) and Omar and Fatah (2021). However, it is noteworthy that most of the studies (Mangika et al. 2009; Nor et al. 2020), which assessed the technical efficiency among coconut smallholder farmers, have reported that the application of fertilizer has no significant effect on coconut production. Rainfall has a positive significant coefficient of 0.43, indicating that a one-unit increment in rainfall will realize a 0.43 increment in coconut output. Labor input is also positive and significant in the estimated model. The plantation sector has employed skilled laborers, and they are continuously supported with necessary training. Hence, the positive effect of labor on coconut output is justified. Tractor hours have a positive significant coefficient of 0.30, indicating that one-unit increment in tractor hour will realize a 0.30 increment in coconut output. Mulching of the coconut trees with fronds had an elasticity of 0.26 indicates that a 1% increase in mulching (one coconut tree) would lead to a 0.26% increase in coconut output. A minimum of 12 fronds fall annually from a coconut tree, and growers use these to thatch the bases of the coconut trees. Mulching can conserve moisture and provide an organic source of fertilizer and thereby enhance the output of coconut. The analysis of the returns to scale can be done based on the estimates of the stochastic frontier production function in Table 2. Determining the scale benefit of coconut production can be done by summarizing the input coefficients other than the agrochemicals and harrowing/plowing factors. The sum of the coefficients is 1.34, which implies that the coconut production system in KPL operates at increasing returns to scale.
The effect of farm and farmer-specific factors on inefficiency was estimated together with the production frontier. The estimated coefficients of the inefficiency model are shown in Table 2. Accordingly, only the size of the estate denoted by bearing coconut extent is the key factor affecting the technical efficiency of coconut plantations. The other variables; viz. agro-ecological zone and the manager's education level, are not statistically significant.
Table 3. Illustrates the mean, minimum and maximum technical efficiency of all the estates belonging to KPL. According to Table 3 mean, minimum, and maximum technical efficiency of the estates belonging to KPL are 88%, 58%, and 99%,

Table 1. Summary statistics for variables in the production function and Inefficiency model

Variable	Obs.	Mean	Std. Dev.	Min	Max
Variables used in Production model					
Yield (nuts)	171	1,620,210.00	752,190.50	408,55.00	3,178,705.00
Rainfall (mm)	171	1,955.89	548.08	1,022.00	3,886.80
Labor (man-days)	171	21,049.87	10,025.29	386.00	45,928.00
Fertilizer (kg)	171	46,896.01	27,854.02	1,200.00	138,783.00
Chemical (L)	171	64.97	69.86	1.00	308.00
Tractor meter hours	171	2,051.28	1,075.27	33.00	4,984.50
Mulching (No of trees.)	171	28,467.08	22,494.6	250.00	148,032.00
Ploughing (ha)	171	27.77	33.30	0.32	235.00
Variables used in Production model					
Bearing extent (ha)	171	380.10	142.81	37.11	669.01

Source: Author's estimates

Table 2. Maximum likelihood estimates for parameters of the stochastic likelihood production frontier and inefficiency models

Variable	Parameter	Coefficient	Std. Error	Z value	P-value
Stochastic frontier					
Ln (Fertilizer)	β_1	0.16***	0.036	4.70	0.00
Ln (Rainfall)	β_2	0.43***	0.10	4.14	0.00
Ln (Labor)	β_3	0.19***	0.062	3.07	0.00
Ln (Chemicals)	β_4	-0.01	0.021	-0.65	0.51
Ln (Tractor hours)	B_5	0.30***	0.082	3.77	0.00
Ln (Mulching)	B_6	0.26***	0.48	5.39	0.00
Ln (Harrowing /Ploughing)	B_7	-0.01	0.26	-0.53	0.594
Year	β_0	-0.02**	0.01	-2.29	0.02
Inefficiency model					
Agro ecological zone	δ_1	-9.96	24.54	-0.41	0.68
Education level	δ_2	-0.19	0.32	-0.61	0.54
Ln (Bearing coconut extent)	δ_3	0.08***	0.62	2.97	0.00
Constant		-1.16	-	-	-
u-sigma – cons		-2.59			
v-sigma –cons		-1.16			
Sigma u		0.272			
Sigma v		0.227			
Inefficiency model					
Likelihood ratio	-8.38				
Probability>Chi^2	0.00				
Number of obs.	171				
Gamma (γ)	0.59				

Source: Author's estimates

Notes: *** $p<0.01$ significant at 1%, **$p<0.05$ significant at 5%, *$p<0.10$ significant at 10%

respectively, which indicates that there is a 12% scope of increasing the production of coconut in KPL without incurring any additional cost.

The outcome of the analysis was compared with other major agricultural products. There was no considerable difference in technical efficiency except the tea smallholding sector (Basnayake and Gunaratne, 2002) and the paddy farming system in the DZ (Udayanganie et al., 2006); other sectors showed efficiency above 70 percent. In addition, several studies estimated technical efficiency, including; Amarasinghe and Weerahewa (2001) on potato production (72%); Gunathilake and Gajanayake (2008) on dairy farms managed by NLDB (71%), Mangika et al. (2009) on coconut sector (74%), Amarasuriya et al. (2010) on pineapple (85%).

Ranking of the estates according to the technical efficiency

Ranking the estates according to the mean technical efficiency is important to identify the best performer and to develop strategies to improve the productivity levels of the estates. The distribution of mean technical efficiency of the estates calculated by weighted average from the pooled data output is illustrated in Fig.1. Accordingly, the Attanagalla estate shows the highest technical efficiency of 98%. In contrast, Katugampola estate shows the lowest technical efficiency of 81%. The mean technical efficiency of other estates varies in between, indicating that there is a potential to increase the estates' technical efficiency.

Table 3. Mean, minimum and maximum technical efficiency

Variable	Obs.	Mean	Std Dev.	Min.	Max.
Technical efficiency	171	0.88	0.0817	0.58	0.99

Source: Author's estimates

Conclusion and Policy Implication

This study used the stochastic production frontier method to estimate technical efficiency and identify the determinants of technical efficiency of coconut plantations. The results revealed that the mean technical efficiency of coconut plantations belonging to KPL estimated using Cobb-Douglas production frontier is 88% indicating that 12% of the maximum potential productivity is lost due to technical inefficiency of the estate-specific characters. Moreover, this indicates that there is a scope for further increasing the output by 12% with a given level of technology and without increasing the level of inputs. The outcome of the analysis suggests that increment application of fertilizer, labor, tractor hours, mulching, and experience of rainfall will significantly increase coconut production. The agrochemicals and plowing/harrowing did not show a significant contribution to coconut production. From the farm and farmer-specific characters, the size of the estate has a positive relationship with technical inefficiency, suggesting that larger estates are less efficient than smaller estates.

The policy implications of these findings are that the technical efficiency of coconut estates could be increased by 12% on average through better use of available resources such as fertilizer, labor, tractor hours, mulching, and supplementary irrigation, given the current state of technology. This could be achieved through awareness programs. The small-scale coconut plantations have more technical efficiency indicating that government and private sector assistance is necessary to improve the productivity of the small-scale coconut plantations. Continuous improvement of the technical efficiency of coconut production could promote income growth and profitability of the plantations. However, this study could only assess technical efficiency in large-scale coconut plantations, which could be extended to smallholders to suit them. The analysis contributes to government policy to expand the small-scale coconut plantation on abounded paddy fields and current debate on the banning of inorganic fertilizer.

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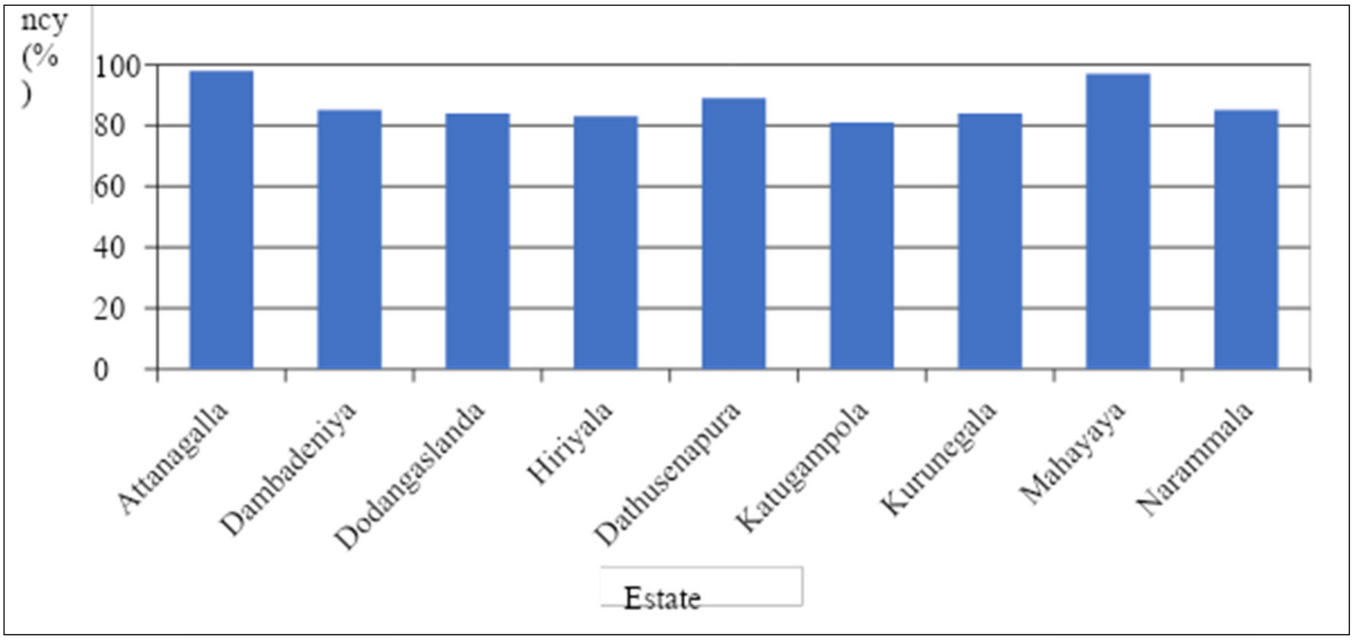

Figure 1. Mean technical efficiencies of area estates (2000-2018)

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Coconut Growers' Knowledge and Perceptions on Climate Change and Adaptation Strategies in Puttalam District of Sri Lanka

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Abstract

Climate change and extreme weather events are significantly affecting the productivity of coconut in Sri Lankan coconut-growing areas, which ultimately will threaten the livelihoods of the coconut-cultivating community. The present study was undertaken to determine coconut growers' knowledge and perceptions about climate change and adaptation strategies. The study was conducted in Puttalam district, which is more vulnerable to climate change impacts in the country using 140 coconut growers as the sample. The findings of the study emphasized that many growers have a fairly high knowledge and informed perceptions about climate change and its impacts. Further, out of five independent variables, namely age, education and farming experience were found to be positively related, while landholding and land ownership were negatively related to coconut growers' knowledge and perceptions on climate change. The higher the educational attainment, the knowledge and perceptions on climate change were significantly higher among the respondents. Moreover, growers' knowledge was positively and significantly associated with their perceptions and adaptation measures. The study highlighted coconut growers' poor adaptation in most of the recommended strategies on climate change. Hence, further studies on other constraints which may limit the proper adaptation of climate change measures should be conducted.

Keywords: Adaptation strategies, climate change, coconut growers' knowledge, perceptions

Introduction

Coconut (*Cocos nucifera* L.) is one of the most widely grown perennial plantation crops in Sri Lanka and is extensively cultivated in all the tropical regions of the world (Somasiri et al., 1994). It spreads over 400,000 ha of land area in all administrative districts of Sri Lanka except those at elevations above 750 masl (Central Bank of Sri Lanka, 2016; Somasiri et al., 1994). Coconut is considered as a multipurpose crop providing food, shelter, oil, medicine, fuel, building materials and beverage. Therefore, coconut is interwoven with the lives of the local people and considered as the "tree of life".

Annual nut production in Sri Lanka was 2,623 million in 2018 (Central Bank Sri Lanka, 2019). The coconut industry generates employment for nearly 500,000 people, contributing to nearly 0.6% of gross domestic production and 1.0% of foreign exchange earnings (Central Bank Sri Lanka, 2019; Liyanage, 1999). It is cultivated in all three agro-climatic zones of Sri Lanka, 30% in the wet zone, 50% in the intermediate zone and 20% in the dry zone. Coconut performs well under a mean annual temperature range of 27°C – 29°C and a mean annual rainfall of 1,250-2,500 mm/year (Ranasinghe, 2012). The main coconut growing area consists of three administrative districts within the "Coconut Triangle"; Kurunegala, Puttalam and Gampaha representing 57% of the total coconut lands. The Southern Province contains about 12% of the coconut cultivated lands and is identified as the "Mini-Coconut Triangle" consisting of Galle, Matara and Hambantota administrative districts. The remaining coconut areas are distributed throughout the country, except for the central upcountry where the climate is not suitable for growing coconut (Department of Census and Statistics, 2002; Karunanayake, 1976).

Effects of Climate Change on Agriculture and Coconut Sector in Sri Lanka

Climate change has been emphasized by the Intergovernmental Panel on Climate Change, IPCC

(2007, United Kingdom, European Commission, Belgian government) as any change in climate over time that arises as a result of both human activity and natural variability. It is an inevitable phenomenon that is being experienced globally in various forms, namely temperature rise, sea-level rise, droughts, floods, hurricanes, landslides and increase in thunder activity due to greenhouse gas emissions (Esham and Garforth, 2013; Goyal, 2004).

Climate change continues to adversely affect the livelihoods of people in developing countries where a large proportion of the population is heavily dependent on agriculture (Esham and Garforth, 2013). Nevertheless, the extent of the impact of climate change on agriculture can be minimized by improving the knowledge level, changing the perceptions and improving the level of farmers' adaptation with climate-smart strategies (Acquah et al., 2011).

Being a tropical country, Sri Lanka is highly vulnerable to the impacts of climate change. Few studies have attempted to quantify the impact of climate change on crops in terms of yield reduction and economic loss (Costa et al., 2003; Fernando et al., 2007; Wijeratne et al., 2007). Lobell, et. al. emphasized that perennial cropping systems are more vulnerable to climate change because they are long-established (Lobell, et al., 2006); but, at present, there are few studies conducted for plantation agriculture.

It is identified that climate change is projected to increase atmospheric CO_2 concentration and temperatures, and affects rainfall patterns. It has been established that the major climatic variables which influence coconut yield are rainfall, evapotranspiration, temperature, solar radiation, sunshine hours, relative humidity and wind velocity. The prevailing total amount of rainfall and minimum air temperature is significantly correlated with the percentage of button nuts shedding (Peiris and Thattil, 1998; Peiris et al., 1995, 2000) which significantly affects nut yield. Also, coconut performs better with no moisture stress, and it performs moderately well where there is a minimum period of moisture stress (Somasiri et al., 1994).

Further, it has been identified that the reproductive development in coconut is more sensitive to high-temperature stress and water stress than vegetative development and the principal harmful effects are reported on nut sets (Coconut Research Institute, 2014). The most important yield-determining factor in coconut is nut setting. Reduced nut setting can be observed due to heat stress and long dry spells in coconut plantations in the dry-intermediate and dry zones, even if irrigation is practiced.

Coconut is perennial in nature and the assessment of the impact of climate change is challenging. Coconut growers' knowledge and perceptions about climate change strongly affect how they deal with climate-induced risks and uncertainties, especially on undertaking specific measures or coping strategies to mitigate the adverse impact of climate change on coconut. Hence, Raghuvanshi et al. (2017) indicated that farmers' perceptions are critical for mitigating the adverse impact of climate change on agriculture.

Coconut growers and coconut cultivation in Puttalam district of Sri Lanka

Puttalam district is situated in the North-Western province and spreads over 3,072 km2 of total lands and 70,983.5 planted hectares (175,404 Ac), totaling around 10.5 million palms. The main agro-ecological zones of this area are Low country Intermediate (IL1, IL3) and Low country Dry (DL1, DL3). The mean annual rainfall is 1,300 mm which varies from 1,200 mm to 1,600 mm and the mean annual temperature is 30.5°C which varies from 29°C to 32°C.

A sizeable proportion of the Puttalam district population mainly depends on the agriculture sector. However, the district has been affected by an extended period of drought and severe heat stress which limits coconut productivity, and ultimately threatens people's livelihoods in rural areas. Hence, the coconut growers of this district are more vulnerable to climate change impacts than growers in other parts of the country.

Methodology

The study was conducted in Puttalam district of Sri Lanka. The study respondents comprised of 140 coconut growers, selected according to a stratified random sampling method representing the district. The heads of the selected households or their spouses were interviewed using both a 10-point Likert scale and a pretested semi-structured questionnaire. Group discussions were also conducted with randomly selected groups of coconut growers in the district. The 10-point Likert scale questionnaire was designed to assess the coconut growers' knowledge, perception and adoption of impacts of climate change. Semi-structured questions were used to elicit socio-demographic information on coconut growers' including level of education, age, gender, years of farming experience, landholding, family size and land ownership.

Coconut growers were provided with a list of 14 statements to assess their knowledge level on the impacts of climate change. Each statement was set against a ten-point "Likert Scale" ranging from 'extremely knowledgeable' (10) to 'extremely poor in knowledge or unknown' (0). This way the respondents' level of knowledge was weighted. Similarly, growers were provided with a list of 32 statements to assess their level of perceptions by indicating their perceptions against a ten-point "Likert Scale" ranging from 'extremely perceived' (10) to 'extremely poor in perception or not perceived' (0). In addition, growers were provided with a list of 13 statements to evaluate the adoption levels of adaptation measures against a ten-point "Likert Scale" ranging from 'extremely adopted' (10) to 'extremely poor in adoption or not adopted' (0) (Advisory Circulars A, B, C series, Coconut Research Institute, 2018).

Once all the responses were coded based on the 10-point Likert Scale, correlation analysis was performed to find out the relationships in coconut growers' knowledge, perception and adaptation level on climate change. The association between independent variables (Age, Land Holding, Education, Farming Experience, Land Ownership) and dependent variables (coconut growers' knowledge and perceptions) was also analyzed. Finally, the impact of independent variables on the dependent variables was determined using regression analysis.

Result and Discussion

Socio-demographic profile of the coconut growers in Puttalam district

This socio-demographic profile of the farm households (Table 1) is believed to have differential impacts on the growers' perceptions about climate change and their adaptation ability. The age of the grower represents their experience in farming. The experienced growers are expected to have a higher probability of perceiving climate change as they are exposed to past and present climatic conditions over a longer horizon of their life span. The majority of the respondents (57.86%) were more than 50 years old followed by 39.28% of growers in the "40-50 year" age category and very low percent (2.86%) of growers were in "30-40 year" age category. Gender-wise, the composition of the study sample reveals that the large majority (85.71%) were males; and that 62.86% of the growers had 2-3 members in their families. As regards land holding, 80.71% of growers had "2-25Ac" category land holding, 17.86% were in the "25-50Ac" category and 1.43% had "50-100Ac" category landholding. Achieving higher levels of education helps growers to access information on improved technology and resources. It is evident that the majority (55%) of growers in the study sample were educated up to G.C.E. (A/L) followed by 22.86% were educated up to G.C.E. (O/L), 17.14% were Diploma or Graduates and only 5% were educated up to Grade 8. As regards their farming experience, 59.28% of the respondents had only "5-10 year" farming experience, the rest (32.14%) had "11-20 year" farming experience and only 4.28% of the respondents have been farming more than "30 years" Further, the majority of respondents (97.86%) reported owning their land.

Table 1. Socio-demographic profile of the coconut growers

No	Variables	Frequency	Percentage (%)
1	**Age (Years)**		
	<30	0	0
	30-40	4	2.86
	40-50	55	39.28
	>50	81	57.86
2	**Gender**		
	Male	120	85.71
	Female	20	14.29
3	**Landholding (Acres)**		
	<2Ac(<0.8ha)	0	0
	2-25Ac (0.8-10.1ha)	113	80.71
	25-50Ac (10.1-20.2 ha)	25	17.86
	50-100Ac (20.2-40.5 ha)	2	1.43
	>100Ac (>40.5ha)	0	0
4	**Family Size**		
	2-3	88	62.86
	4-5	46	32.86
	6-7	6	4.28
	>7	0	0
5	**Education**		
	Up to Grade 5	0	0
	Up to Grade 8	7	5
	Up to O/L	32	22.86
	Up to A/L	77	55
	Diploma/Graduate	24	17.14
6	**Farming Experience (Years)**		
	<5	1	0.71
	5-10	83	59.28
	11-20	45	32.14
	21-30	5	3.57
	>30	6	4.28
7	**Land Ownership**		
	Own	137	97.86
	Common	2	1.43
	Rent/Tenant	1	0.71

Coconut growers' knowledge or understanding about climate change

Clarifying the growers' knowledge about climate change has been a major theme of research on growers' perceptions of climate change. The findings of Yearly (2000) and Lowe et al. (2006) emphasized that public knowledge of climate change has demonstrated that people are sensitive to the information they are given and from whom.

Several key insights appeared when coconut growers were asked about their understandings of climate change. As shown in Table 2, a large majority (90.1%) of the respondents believed that deforestation has a big impact on increasing temperature and ultimately it significantly contributes to climate change. Further, they broadly perceived that human activities are the leading cause of climate change (88.6%) followed by burning fossil fuel as vehicle fuel, oil and gases cause air pollution and increase in atmospheric temperature (81.8%). The emission of greenhouse gases boosts temperature (63.3%) causing a negative impact on climate change. Moreover, 76% and 74.6% of the respondents indicated that rapid urbanization and lifestyle changes, and increase in population growth, respectively affect climate change (74.6%). Heavy application of inorganic fertilizers (especially N containing fertilizers) (55.3%) was also reported to cause climate change.

The vast majority of the growers recognized that they are currently experiencing the impacts of climate change (86.4%) and climate change is a threat to sustainable development (79.1%). In addition, about 66% of the respondents recognized

Table 2. Coconut growers' knowledge or understanding of the impacts of climate change

No	Knowledge on Climate Change Dimensions	Growers' Knowledge (%) (N = 140)
1	Deforestation has a big impact on the increase in temperature	90.1
2	Human activities are the leading factor for climate change	88.6
3	We are currently experiencing the impacts of climate change	86.4
4	Burning vehicle fuels, oil and gases cause air pollution and an increase in atmospheric temperature	81.8
5	Climate change is a threat to sustainable development	79.1
6	Rapid urbanization and changes in lifestyle have an effect on climate change	76.0
7	Increased population growth has an effect on climate change	74.6
8	Climate change leads to coastal erosion	66.6
9	Climate change causes increases in the intensity of extreme weather events (eg: heat waves, tornadoes, cyclones, heavy rainfalls)	65.6
10	Greenhouse gas emission causes boost in temperature	63.3
11	Climate change causes a rise in sea levels	62.5
12	Greenhouse gas emissions have an impact on climate change	62.5
13	Climate change causes changes in wind velocity and wind directions	58.7
14	Heavy use of fertilizers (especially N-containing fertilizers) causes climate change	55.3

Note: sum of percentages does not equal to zero as respondents have multiple answers.

that climate change leads to coastal erosion and increases the occurrence of extreme weather events (eg: heat waves, tornadoes, cyclones, heavy rainfall). Further, 59-62% had recognized that climate change causes a rise in sea levels and changes in wind velocity and wind directions.

Perception of coconut growers about climate change

Perceptions will shape the knowledge, but knowledge also shapes perceptions about an object, phenomenon or event. Adger et al. (2009) indicated that the farmers' perceptions of long-term or short-term climate changes are crucial pre-indicator in the adaptation process. Therefore, coconut growers' perceptions about climate change strongly affect how they understand and deal with climate-induced risks and uncertainties and undertake specific measures to mitigate adverse impacts of climate change on coconut cultivation.

The percentage analysis of coconut growers' perception about different dimensions of climate change was given in Table 3. It could be observed that while surveying in the field, coconut growers' in the Puttalam district were unaware of the term "climate change" or "global warming" and such trends globally, but they well understand overall changes in temperature and rainfall over time.

Table 3 indicates that the majority of the growers (more than 70%) perceived a slight increase in atmospheric temperature over time, changes in precipitation patterns and volume, changing the length of dry periods and rainy periods, slight changes in the monsoon periods as well as inter-monsoon rainy periods. The same majority perceived a continuing decline in coconut yield, yellowing and drooping of more coconut fronds during dry periods, wilting and drying of more coconut fronds during dry periods and lowering of groundwater levels in their estates over the last 5-10 years. Some 37.8% of the respondents perceived the occurrence of inflorescence abortion during dry periods and about 25.7% perceived that more palms died during the dry periods over the last five years.

Studies by Sampei and Aoyagi-Usui (2009) and Akter and Bennett (2009) emphasized that exposure to mass media increases awareness and concern about the damage associated with climate change. Further, Isham (2002) revealed that social capital plays a significant role in information exchange and it is significantly associated with climate-change perceptions. Results showed that 62.8% of respondents have mass-media exposure to climate change and 69.1% reported having access to social capital (farm-to-farm extension and the number of relatives/ volunteer workers in the village). Additionally, 69.3% of growers have perceived an increase in coconut pest and disease infestations during the last 5 years due to climate change. More than half of the respondents also perceived an increase of pest and disease infestations on other agricultural crops during the last 5 years due to climate change.

Based on observations related to climate-change dimensions, it can be concluded that the majority of the respondents have felt that there have been significant changes in various parameters of climate change. The findings of Maddison (2006) emphasized that adaptation to climate change requires a two-step process, 1) farmers should first notice that climate has changed, and 2) they have to identify useful adaptation strategies and then implement them.

Table 3. Coconut growers' perceptions on climate change and its impacts

No	Perception on Climate Change Dimensions (General)	Growers' Perceptions (%) (N = 140)
1	I feel that climate change is really happening	84.8
2	I feel that the atmospheric temperature has been increasing over the past 10 years	80.6
3	I have noticed the change in rainfall over the past 10 years	79.8
4	I have noticed changes in rainfall seasonality over the last 5 years	77.4
5	I have noticed the climate change influences agricultural yields negatively	77.3
6	I have noticed the fluctuation (increase/ decrease) in amount of rainfall over the last 5 years	76.6
7	I think that climate change is more harmful than beneficial, in general	76.3
8	I believe that climate change poses threats to food security	76.1
9	I have noticed longer dry periods and short rainy periods over the last 5 years	75.3
10	I have noticed that NEM and SWM monsoon seasons were not starting at correct time over the last 5 years	73.0
11	I have noticed that increase in heavy rains over the last 5 years	71.5
12	I have noticed that the inter monsoon rains were not starting at correct time over the last 5 years	70.3
13	I have noticed the increase in run off over the last 5 years	64.2
14	I have noticed an increase in drought conditions in different agro ecological regions over the last 10 years	63.0
15	I feel that there is no impact of floods on coconut cultivation over the past 10 years	59.4
16	I fell that there is no impact of floods on livelihood and household over the past 10 years	53.8
17	I feel that there are not any harmful effects to coconut cultivation over the past 10 years due to droughts conditions	6.1
18	I believe that climate change has no serious cause for economic depression to our country	6.1
19	I feel that there is no impact of droughts on livelihood and household over the past 10 years	5.7
	Climate Change Dimensions (On coconut)	
20	I have noticed the decline in coconut yield during last 5-10 years in my estate	73.8
21	I have noticed the yellowing and drooping of more number of coconut fronds during dry periods	73.8
22	I have noticed the falling of more number of button nuts during dry periods over the last 5 years	72.8
23	I have noticed the lowering of the ground water level in my estate over the last 5-10 years	72.0
24	I have noticed the wilting and drying of more number of coconut fronds during dry periods	70.8
25	I have noticed the increase of pest and disease infestations on coconut during last 5 years due to climate change	69.3
26	I have access to social capital (farm-to-farm extension and the no. of relatives/ volunteer workers in the village)	69.1
27	I have exposure to mass media about climate change	62.8
28	I have noticed that changing fertilizer type into organic may help to reduce the effects of climate change	62.7
29	I have not noticed any effect to intercropping under coconut due to climate change over the last 5-10 years	60.8
30	I have noticed an increase in pest and disease infestations on other agricultural crops during the last 5 years due to climate change	56.7
31	I have noticed inflorescence abortion during dry periods over the last 5 years	37.8
32	I have noticed the death of more number of palms during dry periods over the last 5 years	25.7

Adaptation strategies to climate change

Adaptation to climate change is defined as any adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC 2007). There are several potential adaptation options to reduce moderate to severe climatic risks in agriculture. FAO (2010) stated that adaptation options that sustainably increase productivity, enhance resilience to climatic stresses and reduce greenhouse gas emissions are known as climate-smart agricultural technologies, practices and services.

Coconut growers who observed different variations in the climate over 5 to 10 years, were further asked to describe the farm-level adaptation measures undertaken in response to climate change. The results of the study demonstrated that there was a wide range of adaptation measures practiced by the coconut growers in Puttalam district to cope up with the adverse impact of climate change (Table 4).

The study findings indicated that most growers (74.9%) had applied moisture conservation methods in their estates. Further, 62.6% of growers had built and used a hose/sprinkler/drip irrigation system during dry periods to cope with adverse impacts of climate change, 54.1% had used tube wells and 18.6% had practiced manual watering during dry periods. It was observed that 49% had practiced agroforestry system to reduce the temperature in the estate. These findings are supported by Gbetibouo (2009) that building water-conservation/harvesting schemes is a popular adaptation strategy adopted by those who are experiencing the effects of decreased precipitation. The coconut at each stage of nut development is sensitive to soil moisture availability and temperature to varying degrees. Coconuts are primarily grown as a rain-fed crop, and studies showed that the proportion of button nuts (female flowers after fertilization) that fall prematurely from the inflorescence was closely related to total rainfall and the minimum air temperature (Peiris and Thattil, 1998, Peiris et al., 1995). The optimum temperature for pollen germination of coconuts was around 28°C in laboratory studies, while the maximum can go up to 39.7°C (Ransinghe et al., 2015). Relative humidity and temperature also play a key role in nut development (Kumar et al., 2009). The available soil moisture is mainly determined by climate, hydrology and drainage, which is considered key factor that determines coconut production. Further Somasiri et al. emphasized that coconuts perform well in the absence of moisture stress and are produced moderately under a minimum period of moisture stress (Somasiri et al., 1994). The survey showed that 37.6% of the respondents practiced rainwater harvesting methods, 29.1% practiced soil conservation methods and 15.8% had constructed irrigation well in their estates. Furthermore, results revealed that 63.7% had applied organic manure to improve the soil conditions. Specifically, organic manure helps to retain moisture for a long period in the soil as well as increase soil nutrient status. There were 55.2% of respondents who planted drought-tolerant varieties. In addition, 59.1% of growers reported access to agricultural extension services for coconut, intercropping and livestock production. Some (35.5%) even had access to weather forecasting. The survey results revealed that only 2.7% of growers go for off-farm occupation during dry seasons. Dhanya and Ramachandran (2016) emphasized that climate change is recognized as one of the leading challenges affecting the performance of agriculture and associated livelihoods.

Concerning growers' adaptation measures, 10 out of 13 statements adaptation levels were less than 60% (somewhat adopted). Out of these 10 statements, 7 statements hold less than 50% (poorly adapted) adaptation level. This reveals that there may be other possible constraints that limit the coconut

Table 4. Adaptation measures practiced by the coconut growers

No	Adaptation Measures on Climate Change	Adopted growers' (%) (N = 140)
1	Apply moisture conservation methods in the estate	74.9
2	Apply organic manure to improve the soil conditions	63.7
3	Use of hose/sprinkler/drip irrigation system during dry periods	62.6
4	Access to agricultural extension services provided for coconut, intercropping and livestock production	59.1
5	Plant drought-tolerant varieties	55.2
6	Use of tube wells	54.1
7	Practice making agroforestry system to reduce temperature in the estate	49.0
8	Practice rainwater harvesting methods in the estate	37.6
9	Access to information on weather forecasting	35.5
10	Practice soil conservation methods in the estate	29.1
11	Practice manual watering during dry periods	18.6
12	Construct irrigation well in the estate	15.8
13	Go for off-farm occupation during dry seasons	2.7

growers' proper adaptation and capacity to maintain essential adaptation measures to cope with the negative impacts of climate change.

Relationship between Coconut Growers' Socio-Demographic Characteristics and their Knowledge and Perceptions about Climate Change in Puttalam District

Correlation coefficients were calculated to determine the relationship between selected independent variables (Age, Landholding size, Education, Farming experience, Land ownership) and dependent variables such as coconut growers' knowledge and perceptions. After that, a t-test was used to determine the significance of the relationship between the two variables. The results obtained are presented in Table 5.

Findings expressed in Table 5 reveal that out of the five independent variables age, education and farming experience were found to be positively related while landholding and land ownership were negatively related to coconut growers' knowledge levels and perceptions on climate change. However, only the education level was found to be highly correlated with the coconut growers' knowledge and perceptions on climate change. A study by Graft and Onumah (2011) also proved that education has a significant positive effect on the perception of the farmers about climate change.

Table 5. Relationship between Socio-Demographic Characteristics and their Knowledge, Perceptions about Climate Change

No	Independent Variable	Knowledge "Spearman's rho" value	Perceptions "Spearman's rho" value
1	Age	0.153	0.001
2	Land Holding	- 0.030	-0.064
3	Education	0.678**	0.379**
4	Farming Experience	0.111	0.157
5	Land Ownership	- 0.008	-0.023

*** Correlation is significant at the 0.01 level (2-tailed)*

Relationship between Coconut Growers' Knowledge, Perceptions and Adaptation Measures about Climate Change

The correlation coefficient was calculated to find out the relationship among the growers' knowledge, perceptions and their adaptation options practiced (Table 6).

Findings expressed in Table 6 reveal that the coconut growers' knowledge was significantly correlated with their perceptions and adaptation measures. Further, their climate risk perceptions were also found to be markedly related to their adaptation measures.

Table 6. Relationship between Coconut Growers' Knowledge, Perceptions and Adaptation Measures about Climate Change

	"Spearman's rho" value
Knowledge Vs. Perceptions	0.750**
Knowledge Vs. Adaptation measures	0.284**
Perceptions Vs. Adaptation measures	0.289**

***Correlation is significant at the 0.01 level (2-tailed)*

Regression Analysis: Impact of independent variables on dependent variables

Finally, through this study, an attempt was made to find out the association between independent variables (i.e. age, landholding, education, farming experience and land ownership) and dependent variables (coconut growers' knowledge and perceptions) as well as the impact of independent variables on the dependent variables. First, Ordinal Logistic Regression Analysis was done to test the association of independent variables with the dependent variables of the study. The results of the study are shown in Table 7.

Table 7. Association of independent variables with dependent variables

Growers' Knowledge (as dependent variable)		Sig. value
Model Fitting Information		0.000
Goodness-of-Fit	Pearson value	1.000
Pseudo R-square	Nagelkerke	0.758
Test of Parallel Lines		0.000
Growers' Perception (as dependent variable)		**Sig. value**
Model Fitting Information		0.000
Goodness-of-Fit	Pearson value	1.000
Pseudo R-square	Nagelkerke	0.644
Test of Parallel Lines		0.103

As indicated in Table 7, selected independent variables have a stronger association or relationship with the coconut growers' knowledge and perceptions. Further, Multiple Regression analysis was performed and the coefficient of determination (R2) (Table 8) was calculated to find out the contribution of all the independent variables on the dependent variables related to the coconut growers' knowledge and perceptions about climate change.

Table 8 shows that the coefficient of determination (R2) is 0.431 for coconut growers' knowledge about climate

Table 8. Coefficient of determination (R^2) of Multiple Regression Analysis

Dependent Variable	R^2
Coconut Growers' Knowledge	0.431
Coconut Growers' Perception	0.217

change, meaning that only 43.1% of the variation in the dependent variable could be ascribed to all five independent variables considered in the study. With R2 0.217 for coconut growers' perceptions about climate change, so only 21.7% of the variation in the dependent variable could be ascribed to independent variables considered in the study. The remaining 56.9% and 78.3% variations in the respective dependent variables of this study could be ascribed to other factors or variables not considered in this study. Hence, there may be other dominant or extraneous factors that must be studied to arrive at a valid and reliable conclusion about the factors which contribute to the coconut growers' knowledge and perceptions about climate change.

Conclusion

At present climate change has emerged as one of the most prominent factors for coconut cultivation in Sri Lanka. Climate changes and extreme weather events will cause coconut production losses in the major coconut growing areas of the country and ultimately threaten coconut-based livelihoods, which in turn will have adverse effects on national food security as well as the country's economy. The degree, frequency and nature of climatic changes can have serious consequences for coconut cultivation and different farming practices in Puttalam district of Sri Lanka. Hence, to cope with the negative impacts of climate change, practicing suitable adaptation measures is important. This study uses primary farm-level data from Puttalam district in Sri Lanka to analyze the coconut growers' knowledge, perceptions and their adaptive capacities and measures to the changes in climate.

The study findings have highlighted that coconut growers' knowledge and perceptions about climate change are fairly high. They also display a fairly good understanding of various dimensions that contribute to climate change such as rainfall pattern and fluctuations, increase in temperature, changes in rainy periods and monsoon seasons, and several others. However, their low level of adaptation to climate change should be further studied focusing on other constraints which may limit coconut growers' adaptation of practices that can mitigate climate change.

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Estimating Coconut Production and Productivity of Local Tall in Taliabu Island Using Drone and Sampling Population

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Abstract

The objective of this research is to know the local tall coconut population, production and productivity in Taliabu Island, North Maluku Province, which is crucial for the industry. The aerial photography method using drones has been carried out to determine the distribution of coconut diversity, palm age, production potential and local coconut productivity. Production data and coconut fruit components were carried out on 6 sample populations. The result (Arvitech) revealed that in Jorjoga, the area under coconut was 335ha out of the surveyed area of 1,066ha. The total number of coconut palms was 55.728 palms. The Geomac survey carried out in Tabona indicated there were 77,629 coconut palms in an area of 1,000ha. The fruit component analysis showed the weight of the whole fruit and the fruit without husk at the Jorjoga was 1,340-1,629g/fruit, and 805-1,033g/seed nut, and in Tabona was 1,478-1,577g/fruit and 944-966g/seed nut. The coconut production potential at Jorjoga was 9,539 nuts/ha/year, higher than that of Tabona with 7,227 nuts/ha/year. The coconut production and productivity estimation information can be used to develop a coconut replanting and rehabilitation strategy wherein selected varieties with good attributes for the tall coconut can be planted and ensure their proper maintenance, thus can be used to estimate the need for raw materials required for the establishment of the coconut industry in Taliabu Island. Determining the coconut population status can increase the production and productivity of coconut palms through rejuvenation, rehabilitation and expansion of coconut plantations using superior tall coconut seedlings.

Keywords: Local tall, drone, production, productivity, fruit component analysis

Introduction

The coconut palm is a strategic commodity that plays a significant role in people's lives because all parts of the palm are used to meet economic, social, and cultural needs. Nut production for the tall type shows the number of fruits produced under certain agronomic conditions. Meanwhile, the increase in productivity is the increase in the yield of coconut fruits as a result of an improvement in the method of production, as well as the proper utilization of resources. An estimation of coconut fruit production in a coconut plantation is useful for planning purposes to increase the productivity of tall coconuts for use in the production of various coconut derivative products with high economic value. By knowing the potential for production and productivity of the tall coconut in the upstream, the information can be used to plan for the downstream coconut industry in terms of the size of the factory to be constructed, the processing capacity, the kind of machines to be procured and installed, human resource required, and other relevant infrastructure.

For many years, the main output of the coconut sector in the international market was copra, crude coconut oil (CNO) and its derivatives. However, in the last 10 years, we have been able to see new coconut products, the so-called "non-traditional" products entering global exchanges. The market growth of these products, mainly coconut water extracted from mature or immature nuts, virgin coconut oil (VCO) cold-pressed from the fresh kernel, coconut sugar taken from the sap flowing out of the flower, is exponential. The craze for the new products has created big expectations from the consumers towards the coconut stakeholders (Prades, Salum and Pioch (2016). Studies have shown that coconut oil is effective in reducing oral microbial load and decreasing plaque and gingival indices but the number of studies remain a few (Salian, 2018). Destabilization of emulsion in coconut milk brings about the collapse of the emulsion, from which virgin coconut oil (VCO) can be obtained. The yield, characteristics, and properties of VCO are governed by the processes used for destabilizing coconut milk. VCO is considered to be a functional oil and is rich in medium-chain fatty acids with health advantages (Patil and Benjakul, 2018). The statements of the experts above prove that the future of the coconut industry is bright. Thus, if the downstream activities run well and the coconut raw material is sufficient, then coconut production and productivity upstream must also run well and sustainably.

For the local tall coconut variety to be developed it must exhibit some superior characteristics in terms of production and productivity of coconut fruit, among others. In that regard, the coconut variety found in Hainan (*Cocos nucifera* L.) has been proved to have beneficial properties, namely high yield, strong growing stems, and wind tolerance. The local tall coconut variety is the most dominant coconut plant in Hainan Island, the main coconut producing area in China; and is one of the superior coconut varieties being developed (Pan et al., 2018). A survey conducted by Selvamani and Duraisami (2018) to collect soil samples and other basic data from 110 coconut plantations revealed that there exists a relationship between the yield and the soil properties that were determined by the use of correlation coefficient. The highest, positive and significant correlation was observed between soil depth and coconut yield. Among the physical properties studied viz., clay, silt, sand, bulk density, particle density and pore space, a significant and negative correlation was obtained between sand content and yield.

The NICO (Natural Indococo Organic) company one of the estate crops companies in Indonesia has a coconut plantation of around 2,000 hectares in Taliabu Island (Taliabu Regency), North Maluku Province. To obtain accurate coconut production data that is close to real, it is necessary to collect the data at several sample points that are randomly selected, and are representative of the production and productivity of the tall coconut in a plantation. This data is very important to the NICO company to enable proper planning and establish an integrated coconut industry in Taliabu Island.

The purpose of the research was to identify, evaluate and estimate the production and productivity of local tall coconut in Taliabu Island. The information gathered will be used to increase coconut production and productivity by using high input technology to enable the coconut palm to produce high yields per unit area and hence ensure the sustainability of the integrated coconut industry.

Materials and Methods

Study area

The research was conducted in Taliabu Island, Taliabu Regency, and North Maluku Province. The activity was carried out from 1st to 12th February 2021. The location of observation is the Jorjoga site (North of Taliabu Island) and Tabona site (South of Taliabu Island) has around 1,000 hectares or a total of 2,000 hectares. Both of these sites are located near the sea, with an altitude of 5-20 m height from sea level. Some

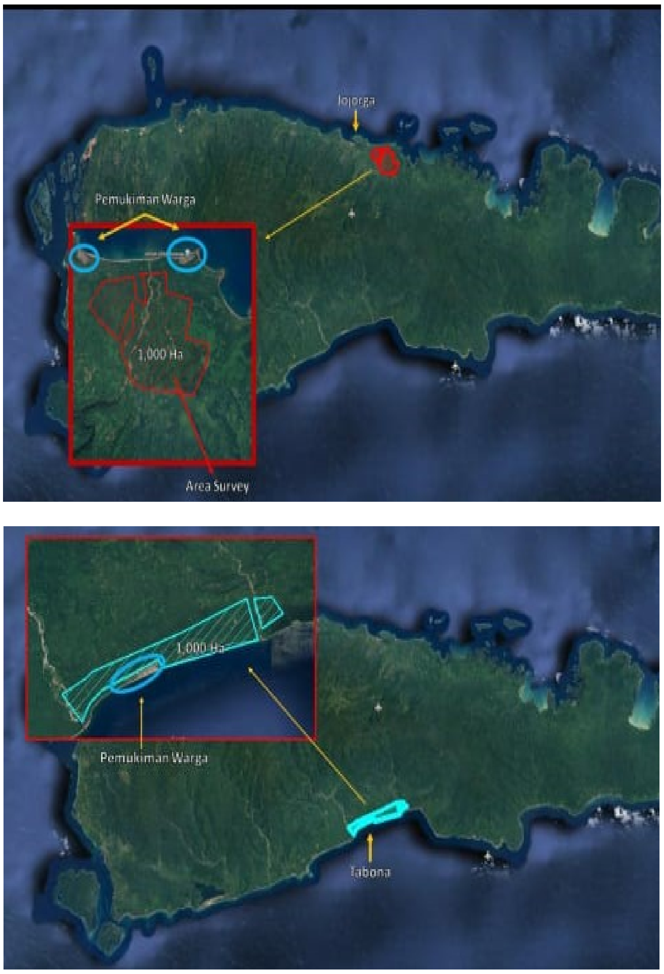

Figure 1. Sites of the survey of the coconut expanse in Jorjoga (left) and Tabona (right) in the North and South of Taliabu Island, Taliabu Regency, North Maluku Province

areas (40-60%) is still consist of secondary forest, bush, and topography a bit hilly.

Methodology

A survey was carried out by two teams (only for using Drone) namely the Avirtech Survey Team that made observations in the Jojorga site, North Taliabu District, and the Geomac Survey Team that conducted its work in Tabona site, South of Taliabu District. Both surveys were carried out by use of aerial photography with a special drone to find out map patterns, topography, number of coconut palms, the health of coconut palms, the types of plants available, the height of the coconut palms, and estate mapping. A third survey team, the HALP Team from NICO company was specifically formed to make direct observations of the coconut plants using the observation methods of STANTECH COGENT (Santos et al., 1997) in Jorjoga and Tabona sites respectively. Materials and equipment used by the teams to make the observations on the coconut plants

Figure 2. Aerial photography by a drone showing the expansiveness of the coconut population with high, medium and low density at the Jorjoga location, and the Tabona location

include a drone, a digital sighting scale, a meter rule, field desk, paint/Phylox, machetes and coconut meat extraction tools. For the Jorjoga site, the survey was conducted in Tanjung Una Village, while for the Tabona site, it was carried out in Maluli Village.

Observations on the production and other components of the tall coconut fruit were carried out by using coconut overlay blocks as a sampling population by the same team. Each location of the survey area (Jojorga and Tabona) was assigned 3 (three) coconut expanse locations randomly and evenly distributed over the area, with the criteria of coconut population at low, medium and high-density growth rates, based on a visual overview of aerial photographs with a drone (Figure 1), After the sample coconut expanse was determined, each coconut expanse was assigned with an area of about one hectare. Thereafter, 30 tall coconut palms of the same age were randomly selected using a diagonal system method. Hence, for the two sites; (Jojorga and Tabona), there were 6 sample coconut populations with a total of 180 palms. All the selected sample palms were marked with colored Phylox paint, with numbers 1 to 30 on the tree trunk, and on the sample fruit for each coconut population sample.

In addition, the following characteristics were observed for each sample palm as per the protocol developed by Santos et al., 1997:

- The number of bunches per palm was done by counting from fully open fruit bunches to the lowest fruit bunch.
- The number of fruit in a bunch is determined by counting the number of fruits in the three oldest bunches of fruits and determining the average.
- The number of fruits/palm/year, namely the number of bunches/year times the average number of fruits/bunch.
- The Fruit component analysis was done by selecting one ripe fruit from each sample palm, and the following parameters for each fruit were recorded:
  - » Fruit shape,
  - » Weight of the whole nut,
  - » Weight of nut without husk,
  - » Weight of nut without water,
  - » weight of meat or endosperm,
  - » Thickness of the coconut meat.

The various parameters of the fruit were determined as follows:

- Weight of whole fruit (g): weighed and calculated the average weight of whole coconuts from sample coconuts,
- Weight of fruit without husk/weight of coconut kernels (g): peeled and husked the nut, then weighed individually and the average weight of the fruit without husk was calculated,
- Weight of seed nut without water (g): coconut seed nuts were split open, the juice was extracted and then weighed,
- The weight of the meat (g): the meat from the coconut which has been split is extracted out using a copra chopper, and then being weighed,
- Husk weight (g), is the difference between the weight of the whole fruit and the weight of the seed nuts,
- The weight of coconut water (g) is the difference between the weight of the whole nut and the weight of the split nut.
- Shell weight (g) is the difference between the weight of the seed nuts and the weight of the coconut meat,
- Thickness of coconut meat (cm), was done by measuring the thicknesses of several nuts and the average was calculated using a sigmat or meter roll.
- Data analysis was performed to determine the average value, standard deviation, and coefficient of variance.

Results and Discussions

Avirtech and Geomac surveyor teams

The first team of the Avirtech Survey reported that the total area that was covered at the Jorjoga location was 1,066ha. The types of plants that were dominant in the area were coconut palms, some cocoa plants, cloves, bananas, other fruit trees and secondary timber forests and shrubs. The area under coconut palms was 335ha, while the remaining area of 731ha had no coconut palms. The results of the aerial photo analysis showed that the height of the coconut palms varied between 1 and 22.23m, with an average height of 7.29m. The number of coconut palms in the area of 335ha was 55,728 trees. The health of coconut palms can be identified from the color of the crown, if the green color is more than 70% it is categorized

Table 1. Observation result of production characters and components of tall coconut fruit with low, medium and high coconut density in Jorjoga and Tabona locations, Taliabu Regency, North Maluku Province

Characteristics	Location of coconut population					
	Jorjoga with level population			Tabona with level population		
	Low	Medium	High	Low	Medium	High
Number of bunches/palm	12	12	13	10	10	10
Fruit/bunch (nuts)	8	8	9	8	7	9
Fruit/palm (nuts)	102	97	110	90	73	89
Weight of whole nut (g)	1,629	1,356	1,340	1,577	1,478	1,507
Weight of nut (g)	1,033	850	805	966	944	994
Weight of husk (g)	596	505	535	612	534	513
Weight of shell (g)	238	204	193	236	244	257
Weight of coconut water (g)	364	270	244	305	289	300
Thick of meat (cm)	1.16	1.15	1.00	1.27	1.16	1.24
Weight of meat (g)	431	380	368	430	411	432

as health, whereas if it is less than 70% it is categorized as poor health.

The second survey team of Geomac on the other hand reported that the total land area that was surveyed was 1,000ha in the Tabona location, North Taliabu District. The coconut palms were sparsely distributed in the upper areas and densely distributed near the river bank. Some areas were covered by the undergrowth of secondary forest trees and other plants. The topography of the area is generally flat and is close to the sea. The altitude is about 5-20m above sea level. The survey, therefore, revealed that the number of palms obtained from the photoshoot was 77,629 trees.

The total number of coconut palms in both sites (Jorjoga and Tabona) was estimated at 133,357 palms. The results of the observations made with aerial photography using the drone can be used for future planning of the land in the two sites for expansion of the area under coconut palms, rehabilitation of existing palms and replanting with superior coconut seedlings among others.

Assessment of coconut palms production and productivity in Jorjoga and Tabona sites

In each location, three sample coconut populations were determined using the criteria of Low, Medium and High coconut palm density. Their growth rates based on aerial photographs with drones are as shown in Figure 2.

The population density per unit area or land stretch is influenced by various factors such as coconut spacing, planting distance, intercropping of plantation crops and the number of palms that are died as a result of pests and diseases, being struck by lightning, or parts of land that are not suitable for palm production, as well as the age of the palms in relation to replanting without logging the old coconut plants.

1. Coconut fruit production and fruit components analysis

The results of observations made on the production and components of coconut fruit at the Jorjoga and Tabona locations are presented in Table 1. From the table it can be seen that the parameters observed starting from the number of bunches per tree, number of fruits per bunch, number of fruits per palm and the weight of the fruit components starting from the whole fruit, weight of fruit without husk, the weight of husk, shells, coconut water, coconut meat and thickness of the coconut meat in the coconut expanse with Low, Medium and High-density levels were recorded. The results showed that the average number of fruit bunches per palm in Jorjoga was between 12-13, while in Tabona the average was only 10 bunches per palm. This number is low especially for Tabona location. In general, Tall coconut palms produce one leaf every month with a fruit bunch at each leaf axil. Hence under normal circumstances, the number of fruit bunches in a coconut should be at least 12 bunches per year.

In certain coconut varieties that are growing on fertile land and sufficient water is available with good cultivation practices, the productivity of coconut palms can be as high as 14-16 bunches per tree per year for the tall coconut varieties.

Furthermore, for the parameter on the number of fruits per bunch at the Jorjoga site, an average of 8-9 nuts per bunch was recorded, while the Tabona site recorded between 7-9 nuts per bunch. The figures on the number of fruits per bunch in the two sites are quite high compared to the acceptable figure of 7 fruits per bunch. In that regard, if for example, the productivity of the coconut palm is at least 12 bunches per palm, then the production of tall coconut is 84 nuts per palm per year, which is considered good.

In Table 1, it is found that the production of local tall coconut at the Jorjoga location is between 97-110 per palm per year, and in the Tabona location between 73-90 nuts per palm per year. When viewed from the differences in the productivity

Table 2. Average, standard deviation and coefficient of variance of production characteristics and fruit components of coconut at Jorjoga and Tabona locations, for low, medium and high coconut population density levels on Taliabu Island, Taliabu Regency, and North Maluku

Characteristics (Jorjoga)	Parameter		
	Mean	SD	CV (%)
Number of bunches/palm	12.32	2.39	20
Fruit/bunch (nuts)	8.40	2.32	25
Fruit/palm (nuts)	103	35.83	34
Weight of whole nut (g)	1,442	270	19
Weight of nut (g)	898	180	20
Weight of husk (g)	543	207	38
Weight of shell (g)	211	41	20
Weight of coconut water (g)	294	100	34
Thick of meat (cm)	1.10	0.14	12
Weight of meat (g)	393	68	17

Characteristics (Tabona)	Parameter		
	Average	SD	CV (%)
Number of bunches/palm	10.26	1.51	15
Fruit/bunch (nuts)	8.03	1.92	24
Fruit/palm (nuts)	84	28	34
Weight of whole nut (g)	1,521	338	22
Weight of nut (g)	968	203	21
Weight of husk (g)	553	212	39
Weight of shell (g)	246	63	26
Weight of coconut water (g)	298	126	42
Thick of meat (cm)	1.2	0.12	9
Weight of meat (g)	424	72	17

of the coconut expanse location based on the density level of Low, Medium and High, it is not that significant.

The weight of the whole fruit in the Jorjoga location is between 1,340-1,629g/fruit, and the weight of fruit without husk is between 805-1,033g/nut. On the side of Tabona location, the weight of the whole fruit ranged between 1,478 and 1,577 grams per fruit, and the weight of fruit without husk was between 944 and 966 grams per nut.

2. Variability of Production and Fruit Component Analysis

The diversity of coconut characters, including the production characters and coconut fruit components, will show how much variation in production and productivity between coconut palms. Table 2 shows the average, standard deviation and coefficient of the diversity of the characteristics of tall coconut at the Jorjoga and Tabona locations. The percentage coefficient of variance (CV%) below 20% indicates a fairly uniform character from each other for coconut palms, whereas if it is above 20% it is classified as having high. The size of the CV value is determined by the size of the standard deviation (SD) to the average value of a character for the plant.

Based on these criteria, it can be said that the characteristics of the coconut population at the Jorjoga location have a CV value of above 20% are those of fruit/bunch, fruit/palm, the weight of husk and weight of coconut water. This means that the diversity of that characters is large enough among the coconut palms. And the other characters, such as weight of the whole nut, the thickness of meat and weight of meat had CV values of 19%, 12%, and 17% respectively, indicating that they are almost similar to each other.

The diversity of production and fruit components of coconut at the Tabona location is almost the same as in the Jorjoga location. In general, characters with a CV value above 20% were found in the number of fruit per bunch, the number of fruits per palm, the weight of husk and the weight of coconut water. The other characters that were below 20% of the CV value, included thickness of meat and weight of meat with CVs of 9% and 17% respectively. Figure 3 shows the diversity of fruit shapes and sizes of fruits for the coconut population at the Jorjoga and Tabona locations. It can be seen visually that the coconut fruit samples at the Jorjoga location are more diverse in shape and size compared to the coconuts sampled from the Tabona location which are somewhat more uniform. The fruit shapes are almost round.

3. The production and productivity of coconut population in Taliabu Island

The average value of each coconut productivity observation location at the Jorjoga and Tabona locations for the three coconut density levels are presented as Low, Medium and High density of coconut are as shown in Tables 3 below. Coconut production in the Jorjoga location was higher than in the Tabona location and stood at 9,539.

Nuts per hectare per year compared to 7,227 nuts/ha/year. Based on the analysis of local tall coconut data at the Jorjoga location which represents the coconut population of North Taliabu District, and the Tabona location which represents South Taliabu District, it can be estimated that the average productivity of the two locations is around 8,383 nuts/ha/year (Table 3). This result is higher compared to the average

Figure 3. Coconut fruits sample from the location of Jorjoga (left) and Tabona (right), Taliabu Island

Table 3. The average number of characters for production and fruit components analysis of local tall coconut at Jorjoga and Tabona locations, Taliabu Regency, North Maluku Province

Characteristics	Average of fruit component analysis		
	Jorjoga	Tabona	Average
Number of bunches/palm	12	10	11
Fruit/bunch (nuts)	8	8	8
Fruit/palm (nuts)	103	84	94
Weight of whole nut (g)	1.142	1.521	1332
Weight of nut (g)	911	968	940
Weight of husk (g)	545	553	549
Weight of shell (g)	212	246	229
Weight of coconut water (g)	293	298	296
Thick of meat (cm)	1,10	1,22	1,16
Weight of meat (g)	393	424	408
Total palm/ha (trees)	186	173	180
Estimation palm productive/ha (nut) x 50%	93	86	90
Estimation production/ha (nut)	9.539	7.227	8.383

productivity of the Indonesian National coconut which is around 4,155 nuts per hectare per year (Alouw, 2020).

If the coconut palms in the Jorjoga and Tabona locations are still in the productive age of 10-50 years, then with good cultivation practices, such as weeding, fertilization, irrigation, control of pests and diseases, it is still possible to increase coconut productivity. Coconut plantations in these two locations appear to be lacking maintenance in several areas, and at the same time, many coconuts grow independently as a result of mature nuts that fall off from the trees and germinate to become young plants of varying age groups within the plantations. These wild-growing plants also have irregular spacing. Weeds and other shrubs on the other hand appear to be growing wild on some of the coconut plantations due to lack of proper routine maintenance. However, some coconut fields are well maintained and with good spacing.

Figure 4 shows an expanse of two coconut plantations in which one of them is quite well maintained and the other one is poorly maintained. Again, Figure 5 shows two sets of coconut palms with high fruit productivity and low fruit productivity respectively.

Coconut productivity can be improved optimally by using improved seed, improved cultural practices, and breeding activities. The breeding program includes selection, evaluation, and utilization of coconut germplasm. The selected good accessions can be released as high-yielding varieties (Novarianto, 2020). In the future, if both locations of Jorjoga and Tabona can be well-developed with a coconut plantation covering an area of 2,000ha, it is estimated that the productivity of coconuts can be increased to a minimum of 10,000 nuts/ha/year. Hence the potential for production in both locations can reach 2,000ha x 10,000 nuts/ha = 20,000,000 nuts/year. The amount of coconut as a nucleus is sufficient for the initial process of building an integrated coconut industry and can absorb coconuts from smallholder farmers. The initial results on farmer perception on the impact of technology intervention, with direct and indirect links to several biological and socio-economic limiting factors, indicate significant improvement across several parameters influencing crop productivity (Thamban et al., 2019). The collaboration between the coconut farming community as plasma and the coconut industry as the nucleus is expected to increase the incomes and welfare of the coconut farmers and the coconut industry, as well as sustainable coconut farming.

Figure 4. Coconut plantations that are well-maintained with regular spacing and that are poorly maintained with varying spacing, and many wild coconuts grow with various age levels of the plant

Figure 5. Coconut palms (left) with high fruit productivity, and coconut palms (right) with low fruit productivity

Conclusion

The drone technology combined with classical sampling population increased the data collection efficiency in tall coconut palms. The technology can cover the data of total areas, types of plants, total areas planted with coconut palms, the phenotypic characteristics such as height of the coconut palms, number of coconut palms, and coconut vigor (healthy, attacked by pests or infected by pathogens). The results of the observations showed that the coconut productivity was about 7.227 to 9.539 nuts /ha/year. The selection of coconut mother trees as a good source of local tall seed nuts can be done on 133,357 coconut palms in both locations (Jorjoga and Tabona, Taliabu Island).

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A Study on Acid Hydrolysis and Composition of Polysaccharides Concentrated from Coconut Kernel

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Abstract

Defatted dehydrated coconut kernel powder (DDCP) is the by-product obtained from virgin coconut oil production through dry process. The aim of the study was to concentrate polysaccharides from DDCP and to investigate their acid hydrolysis capacity and the monosaccharides composition. Residual fat, protein and soluble sugars of DDCP were removed to concentrate coconut kernel Insoluble polysaccharides (CKIP) while water extract of DDCP was used to concentrate coconut kernel soluble polysaccharides (CKSP). Neutral detergent solution (NDS) was used to concentrate neutral detergent soluble polysaccharides (NDSP) and neutral detergent insoluble polysaccharides (NDIP) from CKIP. The acid detergent solution (ADS) was used to concentrate acid detergent soluble polysaccharides (ADSP) and acid detergent insoluble polysaccharides (ADIP) from CKIP. Results indicated fresh coconut kernel contained 7.2±1.5% carbohydrates and the content increased to 78.1±1.3% with the removal of residual fat, protein and sugars. The yields of the polysaccharide fractions were 46.0±3.1% (CKIP) and 9.2± 0.1% (CKSP), 10.2±0.3% (NDSP) and 78.3±4.2% (NDIP), 25.1±0.3% (ADSP) and 45.2±2.9% (ADIP). Trifluoracetic acid had a higher hydrolyzing capacity than sulphuric acid except for hydrolyzing of ADIP. The monosaccharides composition of the polysaccharides was significantly different ($p<0.05$) among the polysaccharide concentrates. The main monosaccharides in NDSP were glucose (73.86%) and xylose (19.7%) and, in ADSP were rhamnose (33.45%) and glucose (46.91%). Rhamnose (29.95%) arabinose (26.38%), xylose (21.56%) and mannose (12.87%) were present in CKSP while mannose (68.46%), galactose (20.59%) and xylose (10.59%) were present in CKIP. Results indicated that soluble polysaccharides of coconut kernel were hydrolyzed into monosaccharides readily compared to the insoluble polysaccharides.

Keywords: Coconut kernel, soluble polysaccharide, insoluble polysaccharides, acid hydrolysis, monosaccharide composition

Introduction

Coconut kernel is an important commodity in food preparation and is a raw material for various food-related industries. Coconut oil and coconut milk are common coconut kernel-based products. Coconut oil production generates by-product of defatted coconut kernels which is mainly used for animal feed. However, these defatted coconut kernels are used for human consumption with improved technology for coconut oil production.

The coconut kernel contains 34-40% fat which is used for domestic cooking, bakery industry, soap and cosmetic industry, margarine-related industries, pharmaceutical industries and traditional medicines. Dehydrated coconut kernel contains 65- 70% fat which can be expelled by leaving nearly 40% of defatted coconut kernels. Therefore, a large amount of defatted coconut kernels is produced in coconut-producing countries like the Philippines, Indonesia, India and Sri Lanka. World coconut oil production is around 3.5 million metric tons (APCC, 2019). Therefore, approximately 2.1 million metric tons of defatted coconut kernels are available for further processing. The defatted coconut kernel produced in the coconut oil industry contains 53.10±0.54% carbohydrates, 4.30±0.01% fat, 25.6±0.2% protein, 5.79±4.74% mineral and 8.8% moisture when it is processed for animal feed (Pavitra et al., 2019). Coconut flour produced from defatted coconut kernel has been incorporated into rice or wheat flour to increase the food value of bread, cookies and muffin (Beegum et al., 2016; Hewa Pathirana et al., 2020 & Ramaswamy & Sinthuja, 2013). However, limited studies have been conducted to utilize defatted coconut kernel as a source of polysaccharides or a food-grade fibre.

Food residues with high carbohydrate content are considered sources of energy and food ingredients (Gosavi et al., 2017). Vegetable and fruit wastes are potential sources for the production of food-grade fibres, pectin concentrates and bioethanol (Maurya et al., 2015;). Breaking down of polysaccharide structure of biomass is needed to produce value-added products like oligosaccharides, monosaccharides, disaccharides and nutraceuticals.

Coconut defatted kernel can be used to obtain polysaccharides to use as an alternative energy source. In addition, polysaccharides could be used to produce monosaccharides, disaccharides and oligosaccharides. Value addition to by-products of coconut oil is very essential to get more income for a sustainable coconut industry. Thongsook and Chaijamrus (2014) modified the physiochemical properties of copra meal, the defatted by-product from coconut oil expelling, using 0.5% HCl to increase its utilization in food applications as a low calory bulk ingredient. Modified copra meal showed improvement in qualities in bread and biscuits.

The objective of this study is to concentrate polysaccharide fractions from defatted coconut kernel which can be hydrolyzed into simple polysaccharides with low-cost techniques such as acid hydrolysis. Coconut kernel polysaccharides have shown prebiotic characteristics (Abbasiliasi et al., 2019, Mohd Nor et al., 2017). Therefore, coconut kernel polysaccharides can be incorporated into food to increase fibre content. Hydrolyzed polysaccharides have more applications in food, pharmaceutical and chemical industries as oligosaccharides, disaccharides and monosaccharides. Due to the compact nature of raw defatted coconut kernel, the acid cannot reach the polysaccharide to hydrolyze them (Becker et al., 2021). Therefore, the raw coconut defatted kernels must be treated with several reagents to remove residual components such as fat, protein and simple sugars to increase the value of fibre and can be processed for variety of polysaccharides isolates.

The findings of this study are benefitted by coconut industry by increasing the value of coconut in the production chain as well as the food and feed industry for the production of food supplemented with coconut-based food grade fibre.

Material and Methods

Materials

Coconuts: Fully mature coconuts were obtained from Bandirippuwa Estate of coconut Research Institute, Lunuwila, Sri Lanka. The coconut was the raw material for the preparation of dehydrated coconut kernel (DCK). Defatted DCK was used to obtain defatted desiccated coconut kernel powder (DDCP) which was the main raw material used in this study.

Reagents

1. Neutral detergent fibre solution (NDS) was prepared according to the methods reported by Vansoest (1963).
2. Acid detergent fibre solution (ADS) was prepared according to the method reported by Vansoest (1963).
3. All other chemicals were of analytical grade unless otherwise specified.

Methods

Dehydrated Coconut Kernel and dehydrated defatted coconut kernel powder: The husks of fully mature coconuts were removed. The outer shells were removed followed by peeling off brown skins. The white kernels were washed with potable water and were left for draining of excess water. The white coconut kernels (CK) were disintegrated to 0.5-1mm thickness and then dehydrated using a cabinet-type dehydrator (Wessburg, Martin; Germany) at 60-65°C. The dehydrated coconut kernels (DCK) were expelled (DD-85 Komet; cold press expeller, Germany) to remove oil and the defatted kernels (by-product) was ground using a laboratory grinder (LG, Korea) into a fine powder. The powder was further defatted using chloroform (1:5 w/v) to yield dehydrated defatted coconut kernel powder (DDCP).

Coconut kernel insoluble polysaccharides: To DDCP (100g), a solution of 0.1N NaOH (500ml) was added and the contents were stirred for two hours. Then the insoluble residue was collected by filtration through double layers of linen cloth. The residue was washed with distilled water until washings were neutral to phenolphthalein. A 500ml of 70% aqueous ethanol was added to the residue and heated to 80°C for 30 min while mixing. The insoluble material in hot aqueous ethanol was collected by filtration through a double layer of linen cloth. The residue remaining (CKIP) after the above procedure was washed with 70% ethanol. CKIP was dried at 70°C.

Coconut Kernel Soluble Polysaccharides: DDCP (100g) was mixed with 400ml of distilled water and allowed to mix for 3 hours. The water extract separated by using a hydraulic pressing juice extractor (Sakaya, Thailand) was added to 4 volumes of ethanol (Proskey et al., 1995; Bao et al., 2001) and left overnight at 4°C to precipitate the water-soluble fibre. After that, the precipitate was collected by centrifugation at 5,000 rpm. The precipitate was freeze-dried to obtain coconut kernel soluble polysaccharide (CKSP).

Concentration of Neutral Detergent Insoluble Polysaccharides of coconut kernel: Coconut kernel insoluble polysaccharides (CKIP) were ground to pass 1mm standard wire mesh (screen). The ground sample (5g) was placed in a round bottom flask with a fitted reflux condenser. Neutral detergent fibre solution (NDS) (500ml) was added to the flask with 0.5g of sodium sulphite and a few drops of n- octanol. The contents were heated and boiled for 60 minutes. After 60 minutes, the soluble and insoluble components were separated by filtration through a cheesecloth. The filtrate was collected separately. The insoluble material (retentate) was washed 3 times with hot distilled water and twice with cold acetone and dehydrated for 8 hours at 105°C to obtain neutral detergent insoluble polysaccharides (NDIP) of coconut kernel.

Concentration of Neutral Detergent Soluble Polysaccharides of coconut kernel: The filtrate of NDIP contains soluble components due to the action of NDS. The filtrate of NDIP was added to 4 volumes of ethanol (Proskey et al., 1995; Bao et al., 2001) and left overnight for precipitation of neutral detergent soluble polysaccharides. The precipitate was collected by centrifugation at 5,000 rpm. The precipitate was freeze-dried to obtain Neutral detergent soluble polysaccharides (NDSP) of coconut kernel.

Concentration of Acid Detergent Insoluble Polysaccharides of coconut kernel: CKIP were ground to pass a 1 mm standard sieve. The ground sample (5g) was weighed into a round bottom flask with a fitted reflux condenser. Then 500ml of Acid detergent fibre solution (ADS) and 10ml of deca-hydro naphthalene were added to the flask. The contents were heated to boiling and the boiling was continued for 60 minutes. After 60 minutes, the soluble and insoluble components were separated by filtration through a cheesecloth. The filtrate was collected separately. The insoluble matter (retentate) in the ADF solution was washed with hot water and then with acetone to isolate insoluble polysaccharides (ADIP) in ADS. ADIP of coconut kernel was dried at 70°C.

Concentration of Acid Detergent Soluble Polysaccharides of coconut kernel: The filtrate of ADIP was added to 4 volumes of ethanol (Proskey et al., 1995; Bao et al., 2001). The contents were left overnight for precipitation of acid detergent soluble polysaccharides. The precipitate was collected by centrifugation at 5,000 rpm, and freeze-dried to obtain Acid Detergent Soluble Polysaccharides (ADSP) of Coconut kernel.

Proximate composition: Proximate compositions of fresh coconut kernel, dehydrated coconut kernel, defatted dehydrated coconut kernel powder and coconut kernel insoluble polysaccharides were determined using the AOAC official method (AOAC, 1990). Carbohydrate composition was calculated by subtracting percentages of moisture, fat, protein, sugar and ash from 100.0.

Determination of the effect of different acids for hydrolysis of polysaccharides

Hydrolysis with Trifluoroacetic acid

The Sample was placed in a flat bottom flask (0.1g of CKSP, NDSP, ADSP and 0.05g of CKIP, NDIP and ADIP). 2M Trifluoroacetic acid (TFA) (10 ml) was added and heated under reflux for 1 hour. Then the contents were cooled to room temperature and filtered through a Whatman 42 filter paper. The filtrate was analyzed for total sugar by phenol sulphuric acid method (Dubois et al., 1956). The experiment was repeated by digesting samples for 2,4,6,8,10 and 12 hours of heating under reflux. Each analysis was carried out in triplicate and the mean values of the total sugar were calculated. Hydrolysis at t=0 was considered as control.

Hydrolysis with Sulphuric acid

The Sample (0.1g of CKSP, NDSP, ADSP and 0.05g of CKIP NDIP and ADIP) was mixed with 1.25ml of 72% (w/w) sulphuric acid with a glass stick for 15 minutes at room temperature. The contents were then diluted with 13.5ml of water and refluxed for 1 hour. At the end of 1 hour, the contents were cooled to room temperature and 3.1ml of 32% NaOH solution was added. The contents were filtered through a Whatman 42 filter paper (Hoebler et al., 1989). The sugar content was determined using the phenol sulphuric acid method (Dubois et al., 1956). The experiment was repeated with 2, 4, 6, 8, 10 and 12 hours of heating under reflux. Each analysis was carried out in triplicates and the mean values were calculated.

The amount of sugar released due to hydrolysis without refluxing was considered as initial sugar hydrolyzed. Time vs the sugar concentration of hydrolysate was plotted and the hydrolyzing capacity of the two acids were compared.

Determination of monosaccharide composition of the hydrolysate

Derivatization of alditol acetates of neutral sugars in cell wall polysaccharides

The cell wall polysaccharides (CKIP, CKSP, NDSP and ADSP) were hydrolyzed separately in 2M TFA (0.1 g of sample in 10 ml of acid) at 100 oC for 14-18 hours. The hydrolysate was filtered through Whatman 42 filter paper. Excess acid in the filtrate was removed by vacuum evaporation and co-evaporation with water to remove all the traces of acids. The hydrolysate containing monosaccharides was converted to alditol acetates using the methods reported by Blakeney et al. (1983). The standard monosaccharides, glucose, arabinose, xylose, mannose galactose and rhamnose of analytical grade were also converted to alditol acetates using methods reported by Blakeney et al. (1983).

Analysis of alditol acetates

Alditol acetates were analyzed using Gas Chromatograph (Agilent 4890D, Agilent Technologies (Pvt) Ltd., USA), Column– DB 23.3mm x 0.32mm x 0.25µm film thickness, Injection volume–1.0µl, Detector–FID, Program–Set temperature–200°C, Initial time–40 min, Final temperature–200°C, run time–40 minutes, Injector temperature–275°C, Detector temperature– 260°C. Sugar alditol acetates were dissolved in chloroform and 1µl was injected into the GC. Individual alditol acetates of standard sugars were injected separately and the retention times were identified. Then the samples were injected and the peaks were identified. The total area under each monosaccharide peak was calculated. Each analysis was carried out in triplicate. The mean values of each monosaccharide were calculated.

Experimental design: All experiments were conducted in a completely randomized design. Mean values and standard deviations were calculated. A comparison of means was carried out with T-test and values with $p<0.05$ were considered significant.

Results

Proximate composition of coconut kernel at various processing stages

Coconut kernel is a rich source of fat. After the oil is extracted, other components; sugar, mineral, protein and

Table 1. Change of proximate composition of fresh coconut kernel with different treatments

Constituent	Composition %			
	Fresh coconut kernel	Dehydrated coconut kernel	Dehydrated defatted coconut kernel	Coconut kernel insoluble polysaccharide
Moisture (water)	41.7±0.2	2.5±0.1	4.2±0.2	6.7±0.1
Fat	40.2±0.4	65.5±0.3	9.2±0.3	2.8±0.1
Protein	4.1±0.2	6.8±0.2	12.6±0.3	11.9±0.9
Sugar	5.6±0.2	6.5±0.2	13.7±0.3	0.4±0.1
Ash	1.2±0.1	3.5±0.1	8.2±0.5	0.1±0.01
Carbohydrates by difference	7.2±1.5	15.2±1.5	52.1±2.2	78.1±1.3

Values are mean ± SD of triplicate analysis

carbohydrates are concentrated in the defatted coconut kernel. The proximate compositions of fresh coconut kernel (FCK), dehydrated coconut kernel (DCK), defatted dehydrated coconut kernel powder (DDCP) and coconut kernel insoluble polysaccharides (CKIP) are given in Table 1.

The fat which is 40.2±0.4% in fresh kernel gets concentrated to 65.5±0.3% after dehydration. When the dehydrated kernel is mechanically expelled to separate oil the fat content is reduced to 9.2±0.3%, while carbohydrates increase from 7.2±1.5% in the fresh kernel to 52.1±2.3% in the defatted dehydrated coconut kernel. Further, with the removal of protein and soluble sugars, carbohydrate increases to 78.1±1.3% in CKIP. In this paper, attention has been given to the concentration of carbohydrates, which are the cell wall polysaccharides of the coconut kernel.

The protein content increases from 4.1±0.2 in fresh coconut kernel to 12.6±0.3 in defatted coconut kernel after oil is expelled. However, the removal of protein using 0.1 M NaOH has not reduced protein content significantly.

Fractionation of coconut kernel insoluble polysaccharides

Figure 1 illustrates the concentration of soluble and insoluble polysaccharides of DDCP. The percentage yields of the different types of polysaccharide fractions of defatted dehydrated coconut kernel (DDCP) are given in Table 2.

The DDCP is further concentrated by removing fat, protein and soluble sugars to obtain 46.0±3.1% Coconut Kernel Insoluble Polysaccharide (CKIP).

Coconut kernel soluble polysaccharide (CKSP) accounts for the soluble carbohydrates, proteins and minerals in the water extract of DDCP, which is 9.2 ±0.1%. The materials which are precipitated in alcohol were isolated as CKSP (Table 2).

The CKIP isolate is fractionated into NDIP (78.3±4.2%) and NDSP (10.2±0.3%) (Table 2). CKIP isolate does not have

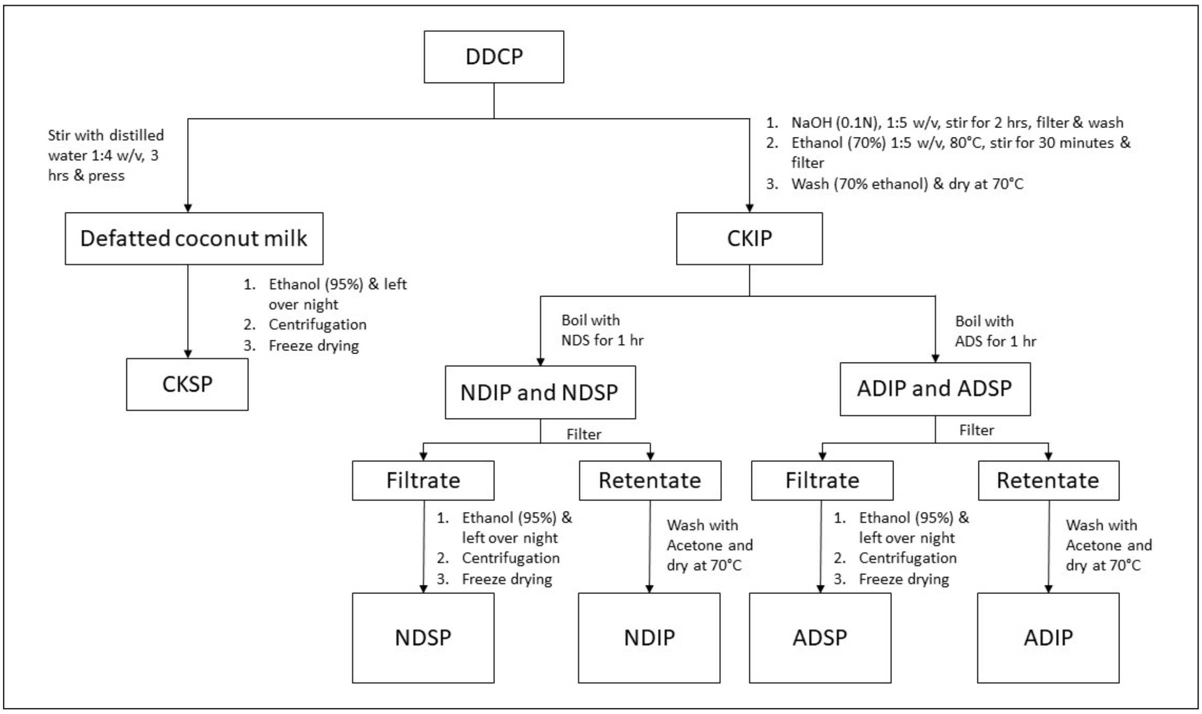

Figure 1. Concentration of coconut kernel polysaccharides

considerable content of soluble sugars (Table 1). Most of the proteins, oligosaccharides and minerals are washed during the isolation of NDIP. CKIP contains lower ADIP content than the content of NDIP. The amount of ADSP was higher than the NDSP. According to Table 2, the total of ADIP and ADSP is 70.3 ± 4% of the CKIP of coconut kernel.

Coconut kernel soluble polysaccharide (CKSP) accounts for the soluble carbohydrates, proteins and minerals in the water extract of DDCP, which is 9.2 ±0.1%. The materials which are precipitated in alcohol are isolated as CKSP (Table 2).

The CKIP isolate is fractionated into NDIP (78.3±4.2%) and NDSP (10.2±0.3%) (Table 2). CKIP isolate does not have considerable content of soluble sugars (Table 1). Most of the proteins, oligosaccharides and minerals are washed during the isolation of NDIP. CKIP contains lower ADIP content than the content of NDIP. The amount of ADSP was higher than the NDSP. According to Table 2, the total of ADIP and ADSP was 70.3 ± 4% of the CKIP of coconut kernel.

Hydrolysis of polysaccharides CKIP and CKSP

Sugar concentrations formed due to hydrolysis of CKIP and CKSP with TFA and sulphuric acid with time are shown in Figure 2. The zero in the time scale shows the amount of sugar released due to the addition of reagent before heat treatment. The concentration of sugars in the hydrolysates of CKIP with sulphuric acid did not increase significantly (P>0.05) during 10 hours of hydrolysis. In contrast, the concentration of sugars increased significantly (p<0.05) due to hydrolysis of CKIP by TFA after one hour compared to the initial point followed by the production of similar amounts at each time interval after one hour.

Table 2. Percentage yield of different polysaccharides concentrated from defatted desiccated coconut kernel powder

Material	Polysaccharides	Yield
DDCP	Coconut kernel insoluble polysaccharides (CKIP)	46.0±3.1%
	Coconut kernel soluble polysaccharides (CKSP)	09.2 ±0.1%
	Total insoluble and soluble polysaccharides in coconut kernel	55.2±3.2%
CKIP	Neutral detergent Soluble polysaccharides (NDSP)	10.2±0.3%
	Neutral detergent Insoluble polysaccharides (NDIP)	78.3±4.2%
	Total soluble and insoluble polysaccharides of coconut kernel due to NDS	88.5±4.5%
CKIP	Acid detergent Soluble polysaccharides (ADSP)	25.1±1.6%
	Acid detergent insoluble polysaccharides (ADIP)	45.2± 2.9%
	Total soluble and insoluble polysaccharides of coconut kernel due to ADS	70.3±4.5%

TFA produced significantly higher concentrations (p<0.05) of sugars due to hydrolysis of CKIP (25.7-32.08 ppm) compared to the amount of sugar produced by sulphuric acid (13.03-20.7 ppm).

The concentration was not significant (p>0.05) until 2 hours when sulphuric acid was used to hydrolyze CKSP. The total sugars produced by sulphuric acid were 60-125 ppm while that by TFA was 75-200 ppm. It was observed that soluble polysaccharides dissolved readily in sulphuric acid and TFA compared to the insoluble polysaccharides. The amount of sugar increased with time when both acids were used, indicating the hydrolysis had to be continued for more than 12 hours for the complete hydrolysis. TFA produced significantly higher sugar concentrations (p<0.05) due to hydrolysis than sulphuric acid did.

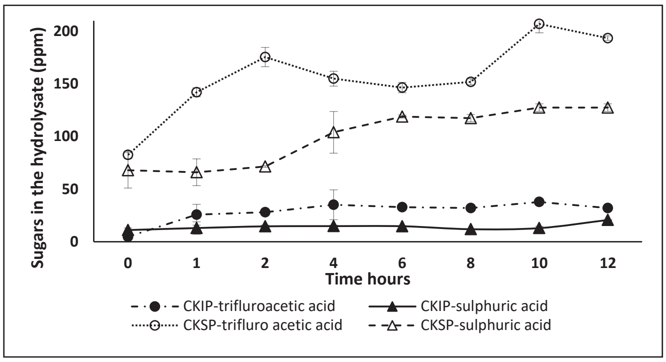

Figure 2. Hydrolysis of coconut kernel insoluble polysaccharides and coconut kernel soluble polysaccharides with time

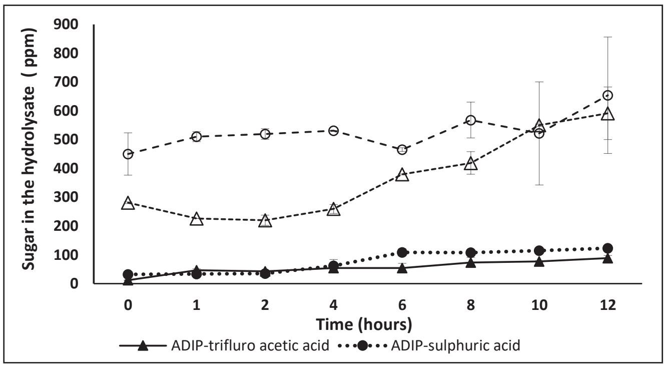

Figure 3. Hydrolysis of acid detergent insoluble polysaccharides and acid detergent soluble polysaccharides with time

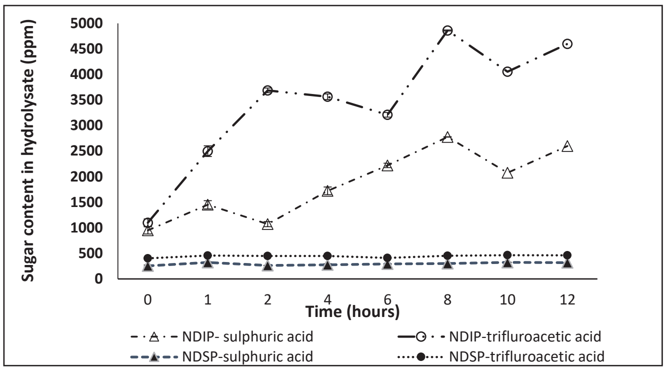

Figure 4. Hydrolysis of neutral detergent insoluble polysaccharides and neutral detergent soluble polysaccharides with time

Hydrolysis of ADIP and ADSP coconut kernel

Figure 3 shows the concentration of sugars produced with time due to hydrolysis of ADIP and ADSP of coconut kernel in the presence of TFA and sulphuric acid.

Figure 3 shows a significant increase in sugar concentrations with time when ADIP and ADSP of coconut kernel were hydrolyzed with both TFA and sulphuric acid. The trends are parallel to the hydrolysis of CKIP and CKSP. The sugar concentration of the hydrolysate of ADIP due to hydrolysis by both TFA and sulphuric acid did not significantly change between 1-4 hours ($p>0.05$) and then, a significant increase in sugar concentration was observed after 6 hours. Similarly, Sulphuric acid produced a parallel trend of hydrolysis but by releasing higher concentrations after 6 hours (108.6–123.0 ppm) compared to 53.8–88.6 ppm released by TFA.

According to figure 3, ADSP of coconut kernel is readily hydrolyzed compared to ADIP. Therefore, ADSP has bonds that are easily hydrolyzed compared to insoluble polysaccharides. Hydrolysis of ADSP with TFA produced significantly higher sugar concentration ($p<0.05$) ranging between 450.07 ppm and 568.0 ppm compared to sulphuric acid (280.8 - 419 ppm) until 8 hours. However, when hydrolysis was continued for more than 8 hours, both acids released more or less similar amounts of sugars indicating both acids had similar hydrolyzing capacity for ADSP with longer durations.

Hydrolysis of NDIP and NDSP of coconut kernel

The figure 4 shows the amounts of sugars formed due to hydrolysis of NDIP and NDSP of coconut kernel using sulphuric acid and TFA with time.

The data showed that significantly higher sugar concentrations ($p<0.05$) were released by hydrolysis of NDIP and NDSP by both TFA and sulphuric acid compared to sugar released by hydrolysis of CKIP, CKSP, ADIP and ADSP by both TFA and sulphuric acid (Figure 2, 3 & 4). In contrast to other isolates, NDIP had higher hydrolyzing power than its soluble polysaccharide counterpart.

TFA produced a significantly higher concentration ($p<0.05$) of sugars (1100–4600 ppm) due to hydrolysis of NDIP compared to sulphuric acid (950–2600 ppm) during 12 hours period. NDSP hydrolyzed significantly lower sugar amounts (255–460 ppm) than NDIP (1100–4600 ppm).

Neutral sugar composition of polysaccharide isolates

The monosaccharide composition of the hydrolysate of the NDSP, ADSP CKIP and CKSP are given in table 3.

Hydrolysates of CKIP, CKSP, NDSP and ADSP contain significantly differing ($p<0.05$) monosaccharides composition of rhamnose, arabinose, xylose, mannose, galactose and glucose (Table 3). The hydrolysate of CKIP contains only xylose (10.59%), mannose (68.46%) and galactose (20.59%). CKSP produced more monosaccharides in the hydrolysate of TFA. It contained rhamnose (29.95%), arabinose (26.38%), xylose (21.56%) mannose (12.87%), glucose (9.2%) and trace of galactose. NDSP produced glucose (73.86%) followed by xylose of 19.7%, arabinose 2.69% and very low concentrations mannose, galactose and rhamnose (1.83%, 1.33% and 0.59% respectively) whereas ADSP is composed of Rhamnose (33.45%), glucose (46.91%), mannose (9.43%), arabinose (3.6%) and galactose (2.36%) and trace amounts of xylose.

Discussion

Polysaccharides of the coconut kernel are concentrated due to oil extraction to produce DDCP without any chemical treatment. Further concentration is possible by removing residual fat, protein and sugar to produce CKIP. The concentration of polysaccharides has been carried out using several organic and aqueous solutions. Among them are hot buffers, chelating agents, dilute and concentrated alkali (Shi, 2016; Im & Yoon, 2015). Insoluble polysaccharides are easily concentrated by dissolving fat, protein sugar and soluble matter from the raw polysaccharides. The concentration of soluble polysaccharides, soluble dietary fibre and pectin should be extracted into aqueous or organic solutions followed by precipitation using 85–96% ethanol (Guo et al., 2019; Bao

Table 3. Monosaccharides in the hydrolysate of neural detergent soluble polysaccharides, acid detergent soluble polysaccharides, coconut kernel insoluble polysaccharides and coconut kernel soluble polysaccharides

Neutral sugar	NDSP	ADSP	CKIP	CKSP
Rhamnose%	0.59c	33.45a	ND	29.95b
Arabinose%	2.69 c	3.6 b	ND	26.38a
Xylose%	19.7b	0.19d	10.59c	21.56a
Mannose%	1.83d	9.43c	68.46a	12.87b
Galactose%	1.33c	2.36b	20.59a	trace
Glucose%	73.86a	46.91b	ND	9.2c

NDSP– neutral detergent soluble polysaccharides;
ADSP– acid detergent soluble polysaccharides;
CKIP coconut kernel insoluble polysaccharides;
CKSP– coconut kernel soluble polysaccharides. ND– not detected;
Different superscripts in rows significantly different at $p<0.05$

et al., 2001; Mohd Nor et al., 2017). In this study, several solutions have been used to solubilize residual matter in CKIP while retaining soluble and insoluble polysaccharides.

CKIP was isolated using chloroform, 70% alcohol and 0.1M NaOH to remove residual fat, sugar and protein in this study. The selection of chloroform to remove residual fat justifies as it removes almost 70% of the fat present in DDCP (Table1). However, other workers used 80% alcohol to de-fat plant material in isolating carbohydrates (Shi, 2016). NaOH is the effective solution to remove residual protein (Yalegama and Chavan 2006) Neutral detergent fibre solution (NDS) was used to solubilize short chain polysaccharides and residual protein bonded to cell wall polysaccharides of CKIP (Vansoest,1963; Chen & Anderson, 1981). The insoluble component of CKIP in NDS was referred to as Neutral Detergent Insoluble Polysaccharides (NDIP). The soluble matter in NDS was isolated using 96% ethanol to isolate soluble polysaccharides and referred to as Neutral Detergent Soluble Polysaccharides (NDSP). Similarly, the insoluble and soluble polysaccharides of the CKIP were concentrated using Acid Detergent solvent (ADS) to isolate Acid Detergent Insoluble Polysaccharides (ADIP) and Acid Detergent Soluble Polysaccharides (ADSP), respectively. Acid detergent solution which can concentrate lignin, cellulose and acid-insoluble hemicelluloses, was developed for the estimation of acid resistant non-digestible material from the plant sources (Chen & Anderson, 1981). The hemicelluloses removed with the ADS contained acid-soluble hemicelluloses that were retained in ADSP (Gosavi et al., 2017; Fahey et al., 2019). The methods for isolation of NDIP and ADIP are based on the analytical procedure to determine neutral detergent fibre and acid detergent fibre from previous studies. However, studies are limited on the use of NDS and ADS to concentrate polysaccharides for food purposes. The present study shows that there is a potential for concentrating soluble and insoluble polysaccharides in coconut kernel with NDS and ADS.

The hydrolysis capacity of insoluble polysaccharides, CKIP and ADIP are very weak compared to the respective soluble polysaccharides. In contrast, NDIP is easily hydrolyzed to simple monosaccharides easily. Chen and Anderson (1981) reported that TFA is more efficient for hydrolysis of insoluble fibre of vegetable sources than sulphuric acid. This result was comparable to hydrolysis of both NDIP and CKIP of coconut kernel because TFA produced more sugar hydrolyzing NDIP and CKIP by TFA.

TFA releases more hexoses and pentoses than sulphuric acid from the insoluble cell wall polysaccharides (Sun et al., 1999) corroborates our study as more sugars were obtained from the TFA hydrolysis of insoluble polysaccharides than by sulphuric acid. Soluble cell wall polysaccharides extracted with hot water were hydrolyzed more readily by sulphuric acid than TFA (Chen and Anderson, 1981). In contrast, coconut kernel soluble fibre was more easily hydrolyzed by TFA than sulphuric acid due to the difference in the method of concentrating. Studies indicated that polysaccharides obtained from neutral detergent fibre solution contain acid-soluble hemicelluloses (Vansoest, 1963). Similarly, NDIP of coconut kernel, in the present study, contains acid-soluble hemicelluloses. The difference in formation sugars may be due to the easily hydrolysable sugars in NDIP of coconut kernel.

A study showed that hydrolysis of polysaccharides by 72% sulphuric acid followed by 8% sulphuric for 10 hours is equivalent to 2M TFA at 120oC for 1 hour. TFA is more suitable for hydrolysis of soluble polysaccharides than insoluble polysaccharides. Fractions of polysaccharides, not hydrolyzed, are the resistant portion for the reagent used for hydrolysis. According to Becker et al. (2021), sulphuric acid can reach the crystalline region of the pure polysaccharides to hydrolyze them. However, strong acid conditions may need to completely hydrolyze the polysaccharide structure. In a heterogenized system like in the present study, readily accessible domains of the polysaccharides will react fast to release monosaccharides into the acid medium. Some of the polysaccharides may be partially hydrolyzed into simpler polysaccharides. The hydrolyzing capacity may also depend on particle size, reaction time and temperature, and the polysaccharide source (Hoebler et al., 1989). Therefore, depending on the strength of acid and particle size of the polysaccharide, time and temperature, some of the polysaccharides may not be hydrolyzed.

The molar ratio of rhamnose: arabinose: xylose: mannose: galactose: glucose of NDSP is 1.0: 4.5: 33.0: 3.0: 2.2: 123.1. According to the molar ratios, NDSP is predominant with soluble glucan or xylose-glucan. The molar ratio of rhamnose: arabinose: xylose: mannose: galactose: glucose in the hydrolysate of ADSP is 167: 18: 1: 47: 12: 234.5 indicating the presence of soluble glucan or rhamnoglucan polysaccharide in ADSP. A higher ratio of mannose compared to galactose indicates the presence of galactomannan-based polysaccharides in ADSP.

The major neutral sugar present in the hydrolysate of CKIP was mannose consisting of 68.46% (Table 3) followed by galactose at 20.56% and xylose10.56% with xylose: mannose: galactose of 1:6:2. However, CKIP was not hydrolyzed completely (Figure 2) due to compact nature (Becker et al., 2021) and therefore, neutral sugars rhamnose, arabinose and glucose may have remained in the residual components. Further, hydrolysis of CKIP reached a constant after about 6 hours (the amount released was not significantly different after 6 hours) and therefore, the conditions were not sufficient to release a fragment with rhamnose, arabinose and glucose. The CKIP contains 11.9% of protein as a residual matter which contributes to the release of less neutral sugars and therefore polysaccharide is not pure enough for detailed studies. The cell wall polysaccharides present in CKIP show resistance to hydrolysis in the presence of sulphuric and trifluoracetic acid as they produced less than 40 ppm of sugar during hydrolysis.

The neutral sugar composition of water-soluble polysaccharides of maturing and mature coconut kernel has been studied using an enzymatic method to break β-D-glucosidic, α-galactosidic and β-mannosidic linkages. The study concluded the presence of 25% galactose and 75% mannose which indicated the presence of galactomannan (Balasubramanium, 1976). According to Saittagaroon et al. (1983), polysaccharides extracted from coconut poonac (defatted copra) using hot water composed of 60% mannose, 17% galactose, 23% glucose and trace amounts of arabinose and xylose. Highly concentrated water-soluble polysaccharides of coconut kernel contained galactose, glucose and xylose as major monosaccharides (Mohr Nor et al., 2017). The observation partially agreed with the neutral sugar composition of CKSP and the difference is due to the difference in concentration of soluble polysaccharides

The polysaccharide fractions concentrated from defatted desiccated coconut powder consist of several short-chain oligosaccharides. The short chain oligosaccharides are considered soluble dietary fibre which shows prebiotic effects in the human digestion system (Mohd Nor et al., 2017). Galactomannan is an oligosaccharide which shows beneficial effects as a prebiotic compound (Majeed et al., 2018). In this respect, ADSP is a fraction of polysaccharide having the potential to use as food-grade fibre. Xyloglucan has proven to be effective in the treatment of acute diarrhoea and also has potential use in the pharmaceutical industry (Genesis et al., 2015; Kulkarni et al., 2017). Therefore, value addition to defatted coconut kernels by concentrating on polysaccharides will be a profitable industry.

Conclusion

Simple techniques were developed to concentrate soluble and insoluble polysaccharides from defatted desiccated coconut kernel. Trifluoracetic acid hydrolyzed coconut kernel soluble and insoluble polysaccharides into monosaccharides more effectively than sulphuric acid. The hydrolysis products indicated the presence of glucan, xyloglucan and galactomannan fragments in the hydrolysate and the coconut kernel polysaccharides developed in this study are likely to have application in food, feed and pharmaceutical industries. Further studies are needed to apply the findings in relevant industries.

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Evaluation of Staple Foods Supplemented with Defatted Coconut Testa Flour

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Abstract

Coconut testa is an important byproduct of coconut processing. This study investigated the acceptability of staple foods incorporated with defatted coconut testa flour (CTF). Food supplemented with CTF will be ideal as a functional food for diabetes. Formulations of string hoppers incorporated with CTF were done by mixing white rice flour (WRF) with CTF in four different ratios; F_1 (WRF:CTF=70:30), F_2 (WRF:CTF=75:25), F_3 (WRF:CTF=80:20) and F_4 (WRF:CTF=85:15). Likewise, formulation of flat-bread *rotti* were prepared by mixing wheat flour (WF) with CTF in four different ratios; P_1 (WF:CTF=60:40), P_2 (WF:CTF=70:30), P_3 (WF:CTF=80:20) and P_4 (WF:CTF=90:10). Acceptability of the formulations was determined by preference ranking test and the data were analyzed using Friedman test and Mann-Whitney test. According to sensory evaluation, the highest score of overall acceptability and other sensory attributes were observed for composite flour mixtures incorporated with 25% of CTF in rice flour for string hoppers (*idiyappa*) and 20% of CTF in wheat flour for flat-bread (*rotti*). The proximate analysis of the finished products namely, string hopper (*idiyappa*) and flat-bread (*rotti*) showed better nutritional properties with regard to protein, dietary fiber, fat and mineral content than the respective composite flour mixtures used in their preparation. Furthermore, string hopper (*idiyappa*) flour mixture [IF, (WRF:CTF=75:25)] and string hopper (*idiyappa*) samples showed increased nutritional compositions in terms of dietary fiber, mineral content when compared to RF [RF, (WF:CTF=80:20)] and flat-bread *rotti* samples. In conclusion, the two-formulated products' quality attributes and dietary fiber content indicated their potential use as anti-diabetic foods.

Keywords: Coconut testa flour, coconut dietary fiber, sensory analysis, anti-diabetic foods

Introduction

Coconut plays an important role in the plantation sector of Sri Lanka. It accounts for 12% of Sri Lanka's total agricultural production. Coconut fruit is considered a valuable part of the coconut tree due to its food and nutritional values and a host of medicinal properties (Deen et al., 2021). The most economically valuable part of the coconut fruit is its kernel, which is covered by a brown layer known as coconut testa (CT) (Ojha et al., 2019). Production of desiccated coconut, coconut milk powder and virgin coconut oil usually require removal of CT from the fresh kernel as a byproduct since it imparts undesirable color to oil and dull appearance to other products (Appaiah et al., 2014). According to some previous estimates, approximately 18 % of the total kernel (w/w, wet basis) is said to be lost during the removal of testa (Gunarathna et al., 2022). Based on the fruit component study by Perera et al (2014), about 6,500 kg of wet CT is generated out of 100,000 nuts of Sri Lankan tall variety. Although CT is an edible bio-waste, it is not yet fully exploited in Sri Lanka as an ingredient for staple food production. At present, it is only used for low-grade oil extraction and the residues are being used for animal feed (Marasinghe et al., 2019). The transformation of agro-byproducts into value-added products has become a global trend these days, which has paved the way for sustainable agriculture (Lucarini et al., 2021). Converting any bio-waste into productive uses is generally in alignment with the United Nations' goals of sustainable development. It exerts a direct and implicit impact on the environment and the economic spheres by minimizing the disposal cost and controlling the escalating value of the finished products (Marikkar et al., 2020). Hence, it is timely to undertake a study on the utilization of CT as a source of food ingredient.

The rising trend in diabetes worldwide has created a new demand for functional foods that would help maintain uncontrolled blood glucose among those with chronic diabetic conditions (Tanko et al., 2021). Apart from the adoption of recommended medications, dietary modification has been recognized as one of the most effective and viable ways to address this health issue (Tanko et al., 2017). Early studies have affirmed that coconut flour made out of defatted coconut kernel residue is a rich source of protein, fat, minerals, dietary fiber and can be a potential raw material for functional food. Hewapathirana et al. (2020) previously found that partially-defatted coconut flour might significantly reduce the glycemic index (GI) of processed food products that help to manage diabetes mellitus. Coconut testa flour (CTF) may also be used similarly for such dietary intervention for diabetes as it is a potential source of antioxidants due to the presence of polyphenols (Arivalagan et al., 2018; Adekola et al., 2017).

Foods with high dietary fiber content have been affirmed to significantly reduce the glycemic index (GI) of processed products (Hewapathirana et al., 2020). Previous studies reported from other parts of the world have indicated that CT generated as a byproduct of coconut would possess antidiabetic properties (Adekola et al., 2022). After subjecting CT to oil extraction, the leftover defatted residue can be crushed into fiber-rich flour, which showed good functional attributes (Marasinghe et al. 2021). According to a nutritional comparison of locally grown coconut cultivars, CTF is found to be rich in protein which is twice the protein content of commercial wheat flour (Marasinghe et al., 2019). A follow-up study indicated that CTF is possessed with anti-hyperglycemic effect in vitro, and thus it is qualified to be called a functional food (Gunarathne et al. 2022). However, a study on the distribution of soluble and non-soluble dietary fiber in CTF obtained from locally grown coconut cultivars is yet to be reported. A recent study showed that defatted CTF can be used as a partial base for wheat flour in producing nutritious cookies (Marikkar et al., 2020). However, CTF from Sri Lankan commercial variety as a partial substitute in major staple foods has not been previously reported. Although wheat flour supplemented with barely flour (Mansoor et al., 2019), soy flour (Khan et al., 2005) and rice bran flour (Saeed et al., 2009) have been already reported from various sources, wheat flour supplemented with CTF in formulating staple foods has been rarely reported previously. Hence, this study aimed to evaluate the acceptability of two staple foods formulated by incorporating CTF into wheat and rice flours. Development and evaluation of staple foods out of these combinations is expected to provide means of maintaining uncontrolled blood glucose among those with chronic diabetes. As such the preliminary findings could be useful as a basis for further study to affirm the effectiveness of the developed products in controlling high blood glucose among those suffering from chronic diabetes through a study in vivo. Furthermore, the proximate analysis data of the novel foods supplemented with CTF could be useful for nutritionists, technologists and future entrepreneurs to explore feasibility of commercialization.

Materials and Methods

Materials and Sampling: Samples of CTF were produced according to the procedure described by Marasinghe et al. (2019) using a commercial hybrid variety of Sri Lanka. In brief, disintegrated fresh testa (moisture content of 42 to 45%) were oven-dried at 70°C using a cabinet-type dryer (Wessberg, Martin, Germany) for 8 h to reduce to 3 to 5% moisture. Low-temperature drying was adopted to minimize severe burning or thermal degradation. Two kilograms of dried testa (medium size particles) were then taken out and subjected to cold press oil extraction using a micro oil expeller (Komet DD85 machine, Germany). The residues left after oil extraction were ground into fine coconut testa flour (CTF) using a commercial grinder (Panasonic, Model:MK-MG 1000). Wheat flour, white rice flour and salt were purchased from the popular commercial enterprises in Sri Lanka.

Methods

Preparation of string hoppers (Idiyappa): Preparation of string hoppers was carried out according to the method described by Malkanthi & Hiremath (2020) with slight modifications. The maximum level of incorporation of CTF into WRF was selected based on the dough consistency and the string hopper brittleness. Hence, the maximum level of CTF that could be incorporated into WRF was identified as 30 %. As the level of incorporation of CTF increased the dough became hard and the resultant string hoppers became brittle. By considering maximum level of incorporation of CTF into WRF, string hoppers were prepared by mixing WRF with CTF in four different ratios; F_1 (WRF:CTF=70:30), F_2 (WRF:CTF=75:25), F_3 (WRF:CTF 80:20) and F_4 (WRF:CTF=85:15) (Table 1). The four flour mixtures were added with warm water to reach proper consistency. After feeding the dough into the string hopper presser, it was squeezed out in a circular pattern onto a steamer mat followed by steaming for 15 minutes.

Preparation of Flat-bread rotti: Preparation of flat-bread *rotti* was carried out as described by Saeed et al. (2009) with

Table 1. Recipe for String hoppers (*Idiyappa*) preparation

Ingredients	Treatments			
	F_1	F_2	F_3	F_4
CTF (g)	210	175	140	105
Rice flour (g)	490	525	560	595
Salt (g)	12	12	12	12
Water (mL)	220	220	220	220

minor modifications. The optimum level of incorporation of CTF into WF was decided considering the dough consistency and the brittleness of the flat-bread *rotti*. The maximum level of CTF that could be incorporated into WF was identified as 40 %. As the level of incorporation of CTF exceeded 40 %, the dough became hard and the resultant flat-bread *rotti* became brittle. Therefore, four different formulations of flat-bread *rotti* were prepared by mixing WF with CTF in different ratios; P_1 (WF:CTF=60:40), P_2 (WF:CTF=70:30), P_3 (WF:CTF=80:20) and P_4 (WF:CTF=90:10), considering maximum level of incorporation of CTF into WF (Table 2). The four flour mixtures were added with 25 % of freshly shredded coconut and 10 g of salt. After adding water to form a sticky dough, kneading was continued until form a soft dough. The resulting dough was cut shape into circles of 0.5 cm thickness on a flat surface followed by baking on a hot pan for 3-4 minutes on each side.

Table 2. Recipe for Flat-bread *rotti* preparation

Ingredients	Treatments			
	P_1	P_2	P_3	P_4
CTF (g)	200	150	100	50
Wheat flour (g)	300	350	400	450
Shredded Coconut (g)	125	125	125	125
Salt (g)	10	10	10	10
Water (mL)	180	180	180	180

Proximate compositional analysis: For proximate analysis, formulated food samples were oven-dried and ground into powders using mortar and pestle. Moisture content was determined using the oven (Gallenkamp, SANYO Gallenkamp PLC, U.K.) method by drying at 105°C for 4 hrs until constant weight is reached (AOAC Official Method 934.06); oil content was determined by soxhlet extraction using petroleum ether (40-60ºC) as solvent (AOAC Official Method 948.22); ash content determination was by dry ashing method (AOAC Official Method 942.05); crude protein content determination by micro Kjeldahl method (AOAC Official Method 970.02). Carbohydrate content was calculated according to the following equation:Total Carbohydrate content (%) = 100 – % (Moisture + ash + protein + fat).

Determination of dietary fiber content: Total, soluble and insoluble dietary fiber contents were determined according to method 991.43 of the AOAC (2019) manual.

Sensory evaluation: The sensory evaluation of the novel products was performed under the previously validated method described by Mansoor et al. (2019). A preference ranking test was performed using a group of thirty semi-trained panelists to select the most preferred formulation out of the four formulations of CTF in terms of preference for sensory attributes namely appearance, color, aroma, taste, texture and overall acceptability. The best formulation selected through the preference ranking test was used for further analysis.

Serving the sample: The samples were coded with three digits random numbers and served to the panelists in random order. The samples were heated at 50°C before the time of serving and the panelists were asked to rinse their mouths after tasting each sample.

Testing criteria: The panelists were asked to assign ranks according to the given scale:1:extremely preferred sample; 2:Moderately preferred sample; 3:slightly preferred sample; 4:least preferred sample based on each sensory attribute for four samples provided and no ties were allowed.

Statistical analysis: The data obtained from the sensory evaluation was statistically analyzed using Minitab 17.1 software package. Friedman test was performed to determine if there is a significant difference ($p<0.05$) among median values obtained for each sensory attribute of four formulations. When a significant difference ($p<0.05$) was identified in Friedman test, the Mann-Whitney test was performed to identify the significant difference ($p<0.05$) between all possible combinations of formulations based on each sensory attribute.

Results and Discussions

Selection of the best flour mixture for string hoppers

The results of the Friedman test performed on sensory attributes of different string hopper formulations are shown in Table 3. There were no significant ($p>0.05$) differences

Table 3. Results of Friedman test along with the rank median of sensory attributes of different treatments

Percentage of CTF	Appearance	Color	Aroma	Texture	Taste	Overall acceptability
F_1	3.44^{c}	2.75^{a}	2.75^{a}	3.88^{b}	3.25^{b}	$2.81^{b,c}$
F_2	1.81^{a}	1.75^{a}	1.75^{a}	2.53^{a}	2.00^{a}	$2.06^{a,b}$
F_3	$2.19^{a,b}$	2.25^{a}	2.25^{a}	1.88^{a}	2.00^{a}	2.06^{a}
F_4	$2.81^{b,c}$	3.25^{a}	3.25^{a}	1.73^{a}	$2.75^{a,b}$	3.31^{c}
CL	*	NS	NS	*	*	*

Rank median bearing different superscriptions are significantly different from each other at a 95% confidence interval level (α=0.05). Abbreviations:CL, confidence level; NS, not significant; *($p<0.05$); F_1, string hopper formulation by rice flour mixed with 30% CTF; F_2, string hopper formulation by rice flour mixed with 25% CTF, F_3, string hopper formulation by rice flour mixed with 20% CTF; F_4, string hopper formulation by rice flour mixed with 15% CTF.

among the formulations with regard to color and aroma, but significant differences ($p<0.05$) were observed between the formulations with regard to appearance, taste, texture, and overall acceptability.

According to Table 3, F_2 (25% CTF) formulation had the highest preference (lowest median) for appearance, color, aroma, taste, and overall acceptability except for texture. For texture, F_4 (15% CTF) formulation scored the highest preference level (lowest median). However, there was no significant ($p>0.05$) difference among F_2, F_3, and F_4 formulations concerning texture attributes. Hence, F_2 (25% CTF) formulation was selected as the most preferred formulation among them. Furthermore, data showed that the preference of the panelists regarding texture attribute seems to be declining with the increasing level of CTF incorporation. This could be due to the grainy texture of CTF which could be improved by further reducing the particle size. For overall acceptability, color and aroma, there were no significant ($p>0.05$) differences between F_1 (30% CTF) and F_2 (25% CTF) formulations. However, significant differences ($p<0.05$) among them were noticed concerning appearance, texture and taste. Furthermore, there was no significant ($p>0.05$) difference between F_2 (25% CTF) and F_3 (20% CTF) for the overall acceptability, color, aroma, taste, and texture. However, a significant ($p<0.05$) difference was noticed between them in appearance. Hence, F_2 (25% CTF) formulation was selected as the most preferred formulation.

Results of the sensory evaluation of the four formulations using the preference ranking test by radar graph is shown in Figure 1. In the ranking test, the lowest median is an indicator of the highest level of preference and as such the lines appearing near to zero in the radar chart indicate the highest preference levels and the preference level gradually declines when the lines move outwards from zero. According to the radar chart in Figure 1, lines representing the medians of all sensory attributes of F_2 (25% CTF) formulation were confined to the area near to zero in the radar chart except for the texture attribute. The median of texture attribute for F_4 (15% CTF) formulation occupied the area near zero on the radar chart. Nevertheless, medians of all other attributes of F_4 (15% CTF) formulation had moved far outwards from zero in the radar chart. Hence, F_2 (25% CTF) formulation was selected as the most preferred formulation for string hopper (*idiyappa*) preparation.

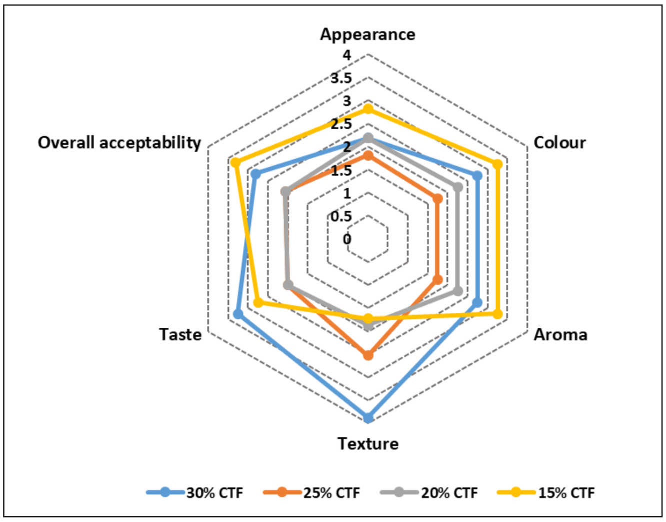

Figure 1. Radar graph for sensory analysis median score values for string hoppers with different proportions of CTF

Selection of the best flour mixture for Flat-bread rotti

The results of the Friedman test performed for sensory evaluation of different flat-bread *rotti* formulations are shown in Table 4. According to Table 4, a significant ($p<0.05$) difference was observed between the formulations regarding color. For texture and taste, highly significant differences ($p<0.001$) were observed between the formulations. Concerning appearance, aroma and overall acceptability, the formulations showed very strong significant ($p<0.0001$) differences.

According to Table 4, P_3 (20% CTF) formulation was found to have the highest preference (lowest median) with regard to color, aroma and overall acceptability. When compared to other formulations, P_4 (15% CTF) showed a significantly ($p<0.05$) higher preference for appearance and taste attributes. However, no significant ($p>0.05$) difference was noticed between P_3 and P_4 formulations with regard to appearance and taste attributes. For texture, P_2 (30% CTF) formulation showed the highest preference

Table 4. Results of Friedman test along with the rank median of sensory attributes of different treatments

Percentage of CTF	Appearance	Color	Aroma	Texture	Taste	Overall acceptability
P_1	3.44^b	3.38^b	2.75^b	3.56^b	3.13^b	3.38^b
P_2	2.81^b	2.75^b	3.50^c	1.94^a	$2.50^{a,b}$	2.25^a
P_3	1.94^a	1.63^a	1.50^a	2.25^a	2.25^a	1.63^a
P_4	1.56^a	2.25^b	2.25^b	2.25^a	2.13^a	2.75^b
CL	***	*	***	**	**	***

Rank median bearing different superscriptions are significantly different from each other at 95% confidence interval level ($\alpha=0.05$). Abbreviations:CL, confidence level; *($p<0.05$), **($p<0.001$), ***($p<0.0001$), T_1, flat-bread *rotti* formulation by wheat flour mixed with 40% CTF; T_2, flat-bread *rotti* formulation by wheat flour mixed with 30% CTF; T_3, flat-bread *rotti* formulation by wheat flour mixed with 20% CTF; T_4, flat-bread *rotti* formulation by wheat flour mixed with 10% CTF.

(lowest median), but no significant (p>0.05) difference was noticed among P_2, P_3, and P_4 formulations with regard to texture attribute. Hence, P_3 (20% CTF) formulation was selected as the most preferred formulation among them. The evaluation of the four formulations using the preference ranking test by radar graph is shown in Figure 2. Here too, the lowest median is considered an indicator of the highest level of preference in the ranking test. As such, the lines appearing near zero in the radar graphs indicate the highest preference and the preference level gradually declines when the lines move outwards from zero. According to Figure 2, data lines representing medians of all sensory characteristics of P_3 (20% CTF) formulation were confined to the area near to zero of the radar chart except for appearance and texture attributes. The median of texture attribute for P_2 (30% CTF) formulation and the median for appearance attribute for P_4 (10% CTF) formulation occupied the area near zero of the radar chart. However, medians of all other attributes such as taste, color, aroma, and overall acceptability for P_2 (30% CTF) and P_4 (10% CTF) formulations had moved far outwards from zero in the radar chart. Owing to these reasons, P_3 (20% CTF) formulation was selected as the most preferred formulation for flat-bread *rotti* preparation.

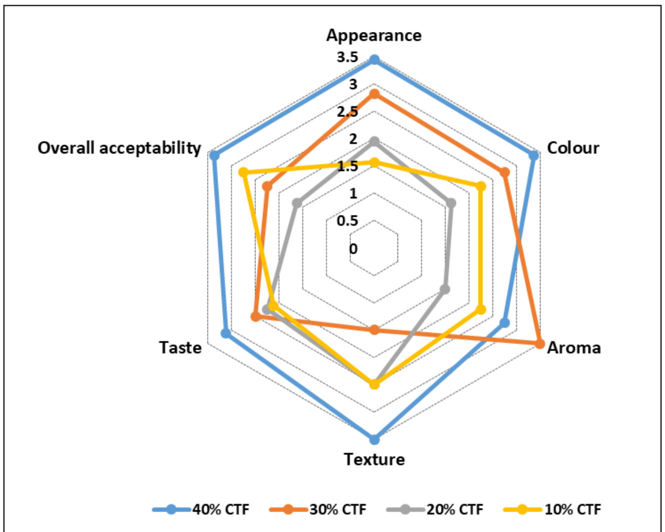

Figure 2. Radar graph for sensory analysis median score values for flat-bread *rotti* with different proportions of CTF

Proximate composition of products

The proximate compositional data of the staple foods supplemented with CTF could be useful for nutritionists, technologists, and future entrepreneurs to explore the feasibility of commercialization. As shown in Table 5, proximate compositions of the best-selected string hopper and flat-bread *rotti* were compared with composite flour mixtures (IF and RF respectively) used in their preparations. In Sri Lanka, string hopper and flat-bread *rotti* are usually prepared with rice flour and wheat flour, which are low in protein and dietary fiber content. The potential benefits of CTF supplementation in staple food production had been realized due to some important nutritional attributes of CTF reported recently (Marasinghe et al., 2019). The data presented in Table 5 shows the improvements brought by CTF supplementation in string hopper and flat-bread *rotti*. The moisture content of composite flour mixtures namely, IF (8.64 %) and RF (11.01 %) were lower than those of the finished products such as string hopper (26.00 %) and flat-bread *rotti* (28.29 %). The increase in moisture contents of the finished products, as noticed from the data would adversely affect the shelf-life stability of crude protein and crude fat. Based on the data, CTF having the least moisture content (6.06 %) would be advantageous for its longer shelf life.

Ash content is a measure of the mineral quantity of samples. Calcium, phosphorous, potassium, magnesium, zinc, copper, and iron are some of the minerals in flour (Czaja et al., 2020). According to Table 5, CTF having the highest mineral content (5.75 %) would contribute to increased nutritional properties. The ash contents of the composite flour mixtures, namely IF (1.91 %) and RF (2.01 %) were lower than those of their respective final products such as string hopper (2.11 %) and flat-bread *rotti* (2.54 %). Thus, it was apparent that cooking increased the ash content of the food products. Among the samples, CTF was found to possess the highest protein content (20.75 %) while the protein contents of composite flour mixtures namely IF (10.47 %) and RF (11.89 %) were slightly higher than their respective finished products, namely string hopper (9.94 %) and flat-bread *rotti* (10.36 %). According to the fat analysis, CTF had a fat content of 9.03 % and fat contents of composite flour mixture IF (2.16%) were slightly higher than that of string hopper (1.09%). However, the fat

Table 5. Proximate composition of flour mixtures and products (g/ 100g; wet basis)

Samples	Moisture (%)	Ash (%)	Fat (%)	Protein (%)	Carbohydrate (by difference)
String hopper	$26.00^d \pm 0.01$	$2.11^c \pm 0.01$	$1.09^a \pm 0.05$	$9.94^a \pm 0.04$	$60.86^b \pm 0.02$
Flat-bread *rotti*	$28.29^e \pm 0.01$	$2.54^d \pm 0.00$	$3.09^d \pm 0.09$	$10.36^b \pm 0.01$	$55.72^a \pm 0.04$
IF	$8.64^b \pm 0.00$	$1.91^a \pm 0.01$	$2.16^b \pm 0.04$	$10.46^c \pm 0.02$	$76.83^e \pm 0.03$
RF	$11.01^c \pm 0.00$	$2.01^b \pm 0.01$	$2.75^c \pm 0.01$	$11.89^d \pm 0.11$	$72.34^d \pm 0.03$
CTF	$6.06^a \pm 0.00$	$5.75^e \pm 0.03$	$9.03^e \pm 0.00$	$20.75^e \pm 0.06$	$58.41^c \pm 0.05$
CL	***	***	***	***	***

Each data in the table represents mean of triplicate analysis. Means in the same column bearing different superscript are significantly different (p<0.05) from each other. Abbreviations:***(p<0.0001); IF, String hopper (*Idiyappa*) flour mixture formulation by mixing rice flour with 25% of CTF; RF, Flat-bread *rotti* flour mixture formulation by mixing wheatflour with 20% of CTF; CTF, Coconut testa flour.

content of RF (2.16 %) flour mixture was slightly lower than that of flat-bread *rotti* (3.09%). This could be partly due to the incorporation of shredded coconut in the case of flat-bread *rotti* preparation. Furthermore, the carbohydrate content of composite flour mixtures namely, IF (76.82 %) and RF (72.34 %) were greater than their respective finished products such as string hopper (61.16 %) and flat-bread *rotti* (55.72 %). Based on the data, strong significant ($p<0.001$) differences were observed among all samples with respect to each of the proximate parameter. Compared to the composite flour mixtures used in their preparation, the finished products, namely, string hopper (idiyappa) and flat-bread (*rotti*), showed some enhanced nutritional properties regarding fat and mineral contents.

Dietary fiber contents of products

Results in Table 6 compare the total, soluble and insoluble dietary fiber content of samples. The dietary fiber component is essentially a part of the carbohydrate that shows resistance toward absorption and digestion in the small intestine, but it undergoes either partial or complete fermentation in the large intestine (Ranaet al., 2011). Both the soluble and insoluble dietary fibers have been reported to have numerous health benefits (Lattimer and Haub 2010; Ranaet al., 2011). According to data in Table 6, among the samples, the total, soluble and insoluble dietary fiber contents of CTF were 65.05 %, 19.02 %, and 46.04 %, respectively. The total and soluble dietary fiber contents of composite flour mixtures of IF (string hopper flour mixture) and RF (flat-bread *rotti* flour mixture) were significantly ($p<0.001$) higher than those of their respective finished products namely, string hopper (*idiyappa*) and flat-bread (*rotti*) samples.

It is clear from Table 6, a greater portion of the total dietary fiber of the samples is constituted with insoluble dietary fiber. Moreover, its content in string hopper (14.08 %) and flat-bread *rotti* (12.03 %) were significantly ($p<0.05$) greater than their respective composite flour mixtures IF (13.13 %) and RF (10.26 %). According to some previous research studies, an increased amount of insoluble dietary fiber content in the human diet would undoubtedly reduce appetite, constipation and risk of type 2 diabetes (Stewart 2014). Consumption of insoluble dietary fiber-enriched diets may help in the control of hemorrhoids and constipation while eliminating extra bile acids and toxins. It would also provide other health benefits including protection against some colon-related cancer (Nur Ain Najwa et al. 2021; Anderson et al., 2009).

The techno-economic feasibility is a critical aspect of the commercialization of CTF-related products. The technology for the production of CTF in this study is exactly similar to the production of defatted coconut flour through the mini-cold pressed oil extraction technology previously described. Nevertheless, machineries are needed to convert the defatted residue into flour after separating testa oil from CT. First of all, a medium-sized grinding machine is required to crush the defatted testa residues into powder form. A sieve shaker is inevitably required to separate the finer flour particles from the bulk crushed residues. This is required because the presence of bigger fibrous matter might affect the palatability of the flour and the finished products. It is this fibrous matter which prevents the direct use of whole CTF in products, but instead, if it can be blended with wheat flour the palatability can be improved. The microbiological stability of the blended flour (CTF: WF) should be undertaken to determine the stability of the flour in an extended period of storage under ambient temperature conditions.

In this study, the novel formulations developed were evaluated by a group of trained panelists, but it may be worthwhile to cross-check the validity of the findings by a group of professional chefs and food consultants. Despite the consumer acceptability of the novel product formulations, they should be subjected to cost-benefit analysis and feedback through cross-sectional surveys. For instance, seeking the opinion of the consumer public and the stakeholders of the coconut industry could be highly useful for commercialization. Without seeking feedback or opinion through an *ad hoc*-selected manner, a cross-sectional survey should be administered through a structured questionnaire and the opinions of the stakeholders of the coconut industry can be obtained separately. For cost-benefit analysis, the calculations for an eight-hour day shift in a small-scale operation should be done using proper agricultural economics procedure.

Table 6. Total, soluble and insoluble dietary fiber contents of flour mixtures and products (g/ 100g wet matter basis)

Samples	Total Dietary Fiber (%)	Insoluble Dietary Fiber (%)	Soluble Dietary Fiber (by difference) (%)
String hopper	14.23b±0.19	14.08d±0.15	0.14a±0.04
Flat-bread rotti	12.26a±0.28	12.03b±0.05	0.22b±0.23
IF	16.56d±0.06	13.13c±0.04	3.43c±0.01
RF	15.15c±0.06	10.26a±0.02	4.94d±0.05
CTF	65.06e±0.21	46.04e±0.07	19.02e±0.14
CL	***	***	***

Each data in the table represents mean of triplicate analysis. Means in the same column bearing different superscripts are significantly different ($p<0.05$) from each other. Abbreviations:IF; String hopper (*Idiyappa*) flour mixture formulation by mixing rice flour with 25% of CTF, RF; Flat-bread *rotti* flour mixture formulation by mixing wheat flour with 20% of CTF, CTF; Coconut testa flour

Conclusions

This study demonstrated that string hoppers (*idiyappa*) and flatbread (*rotti*) of acceptable quality could be prepared using composite flour mixtures of 25% of CTF in rice flour and 20% of CTF in wheat flour, respectively. This was based on the highest overall acceptability and other sensory attributes observed from a sensory evaluation. The proximate analysis of the finished products such as string hopper (*idiyappa*) and flat-bread (*rotti*) showed improvements in nutritional properties with regard to protein, dietary fiber, fat, and mineral contents when compared to respective composite flour mixtures used in their preparation. In terms of dietary fiber and mineral contents string hopper (*idiyappa*) sample's nutritional composition was better than that of flat-bread *rotti* samples. As all samples were reported to have a higher percentage of insoluble dietary fiber than soluble dietary fiber, these products would exert tremendous prebiotic health benefits.

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