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Research Article

Weed Management Strategies in *Colocasia esculenta* Field Caused by *Phytophthora colocasiae* and Global Climate Change

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Abstract

Food losses due to weed infestation in taro fields are major issues of agriculture at the global scale in the recent outbreak of *Phytophthora colocasiae* and the increasing impact of climate change associated with high erratic rainfall conditions. The high rate of weed infestation has been a serious problem to taro farmers and researchers since the arrival of *Phytophthora* leaf blight disease and the recent effect of climate change associated with high erratic rainfall conditions during the peak growth and development of taro resulting in high weed infestation in highly defoliated taro fields. These factors have reduced the unique attributes of taro as shade tolerant and weed suppressive crop in the present taro cropping systems resulting in low yields if weed management strategies are not effectively adopted. Proper weed management option has been a very essential cultural operation for improved taro production and pests/disease incidence and severity reduction. Therefore, a review on measures to manage high weed infestation in defoliated taro field caused by *Phytophthora* leaf blight disease and climate change have been discussed in detail in light of well-documented research findings, conferences/workshops of the past and observation from many experienced taro producers and field extension workers.

Key words: Taro, weed management, *Phytophthora colocasiae*, climate change, food scarcity, agroforestry, interplanting potential, waterlogged soil

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INTRODUCTION

Field losses due to weed infestation in taro fields are major issues of agriculture at the global scale in the recent outbreak of *Phytophthora* leaf blight disease and increasing effect of climate change associated with high erratic rainfall conditions at the peak growth cycle of taro in the growing regions. Under field conditions, weed infestation is among the most destructive of taro fields in the growing regions of South-East, South-West, South-South and the middle parts of Nigeria. The prevalent low taro yield could be attributed to weed infestations among other factors due to defoliating effect of *Phytophthora* leaf blight disease and increasing climatic change impact associated with high erratic rainfall conditions, especially at the maximum growth periods of taro at 3-5 months after planting[1].

In Nigeria, root and tuber crops are the main source of calories accounting for over 50% of the calories intake of the southern parts of the country[2]. *Colocasia esculenta* L. rank third in importance among the root and tuber crops of economic value, in terms of production and land under cultivation in Nigeria after cassava and yam, second and first in Cameroon and Ghana, respectively[3]. Taro parts are extensively consumed by poor income resource farmers, large families in the growing areas of the country[4]. However, the production of taro is no more for poor income resource farmers, poor women and large families. Also, its consumption system has been transforming from food scarcity, large families, economic stress food and poor income resources families to wealthy and high-income resources families and ceremonial/social function food for both poor and rich income resource classes due to its nutritional, medicinal and socio-economic benefits.

Traditionally in Nigeria, the taro production system is mainly home/backyard garden crop and mostly grown with other crop species in the agroforestry system. *Colocasia* spp., has been popularly regarded as water-logged soil, shady tolerant and weed suppressive crop and as well with a high degree of intercropping, mixed cropping and interplanting potential. Anikwe *et al*.[5] reported that taro is an ecologically unique crop due to its ability to grow in ecological conditions like waterlogged soil and shaded environment which other crops may find adverse. Moreso, *Colocasia* spp., is regarded as an erratic rainfall tolerant in the past before the outbreak of *Phytophthora colocasiae* in the growing regions.

Taro is important food security, income generation, medicinal and socio-economic crop in Nigeria which can be grown either solely, intercropped, mixed or interplanted in upland or wetland with okra, maize, pumpkin, fluted pumpkin, cassava, pepper, *Amaranthus* spp., oil been a seed, breadfruit trees, kola nut trees and other non-economic crops[3,4]. Moreso, *Colocasia* spp., provided agroforestry services among farmers in the producing areas, especially in the Nsukka Agricultural Zone, Enugu State, Nigeria. Agroforestry practice has been an adapted and sustainable practice in Nsukka agro-ecological regions for taro farming in the past before the arrival of taro leaf blight.

In the past, the growing of taro in polyculture systems have been recommended due to their more efficient use of vertical space, high weed suppressive nature at 4-5 months after planting, reduced risk of total crop failure resulting from pests and diseases or adverse climatic/weather extremes among others. However, polyculture production of taro reduces photosynthesis due to the shading effect, thereby reducing yield in the cultivated areas and increasing the skill needed for complex field management systems. Also, the outbreak of *Phytophthora* leaf blight disease in the growing areas has narrowed the taro field growth environmental bio-diversity[6]. Most of the reserved, over planted and high fertile/productive soil areas with economic and non-economic trees are no longer suitable for taro production since the arrival of *Phytophthora* leaf blight disease in addition to present high rainfall conditions. Many of the traditional food plants of the pacific are losing their position in the traditional cropping systems because of historical and environmental factors and their genetic vulnerability to pests, weeds and diseases that result in rapid deteriorative performance. Moreso, the majority of the Polynesia and Micronesia cultivation of taro derived from a narrow gene base are very susceptible to today's pests, weeds and disease infestation.

The polyculture potential of taro in the provision of agroforestry system has encouraged the growth and development of *Phytophthora* leaf blight disease incidence and severity due to enhancement of more microclimate favourable for the manifestation of the leaf blight pathogen in taro fields leading to high weed infestations in the defoliated taro fields. The microclimate/environment created by these traditional farming systems supports the incidence and severity of taro leaf blight disease and subsequent high rate of weed infestations in the defoliated taro fields. The adaptability of taro to the traditional farming systems are no longer encouraging and thing of the past with the recent arrival of *Phytophthora* leaf blight disease globally in the growing areas as a result of continuous after raindrop effects under tree shady environment, high cold soil moist and air night/daily temperatures, low free air movement, poor direct sunlight intensity supply, reduced growth space etc. *Phytophthora colocasiae* is a serious foliar disease under certain environmental conditions of high relative humidity, continuous light rainfall and night and daily temperatures of 20-21°C and 25-28°C, respectively whereas warmer and open areas with free air circulation are relatively free from the disease[7,8]. To reduce the incidence of *Phytophthora colocasiae*, planting of taro in shady locations should be avoided and proper drainage must be provided through mounding and re-mounding. These promote full direct sunlight intensity supply with less soil water at growing stands. These local weathers enhance the manifestation of leaf blight incidence and severity and subsequently high weed infestations leading to more decay or death of highly blighted taro leaves, petioles and finally total tuber yield losses[8]. The intensity of leaf blight disease damage depends on prevailing weather conditions and weed management strategies during the taro growth period, being more in the years of abnormal relative humidity, shady and sheltered localities than in open and regularly weed controlled fields[8]. The regular period of leaf and soil wetness under polyculture systems particularly in the warm humid tropics favour pathogen's dispersal, growth and infection and subsequent high weed infestations due to less taro canopy formation in the infected taro fields.

However, the production of taro under open fields without other economically and non-economically trees with regular/proper weed management will create more favourable environmental conditions like adequate direct sunlight supply, adequate free air/wind movement, less after rainfall drop effects, increased air and soil temperatures that may inhibit the growth and development of the zoospores and sporangial sporulation and low weed proliferation in the taro fields. Several studies have shown that the production and the productivity of taro in Nigeria have been declining in recent years as yield less than 18 metric t h^{-1}, limiting the ability of the crop to achieve its traditional roles in economic development, nutritional and medicinal values[4]. Weeds constitute a major limiting factor to crop production in Nigeria as their management is problematic and expensive, time-consuming and less attractive. Weeds compete with crops for growth resources like light, soil water, nutrients, space etc and promote high pests and disease incidence and severity. Uncontrolled weeds in taro result in yield loss of 60-76%[1]. Weed management remains a major problem in taro production and is a very essential part of improved production technology in crop[9]. The productivity of taro can be improved through the adoption of proper weed management strategies by the producers under the recent outbreak of *Phytophthora colocasiae* and the increasing effect of climate change associated with high erratic rainfall conditions.

The most recent appropriate weed management strategies are effective approaches in reducing the field losses in the taro production programme. Therefore, a review of the number of available strategies which are instrumental to managing recent high weed infestations in taro fields is discussed in detail below.

Preventive strategies: Seed production of annual or perennial weeds should be discouraged or prevented by mechanical ploughing, harrowing or any other means by cultural practices like crop rotation especially weed plants before flowering and seed set for late-season planting, controlled bush burning, bare fallowing. The reduced seed bank will create easier next year's weeds management. This practice will also enhance the green manuring of the farmland if the practice is done at the full and tender vegetative phase of the weeds before flowering initiation.

Physical/mechanical weed management strategies: The use of simple manual labour by hoe, cutlass or handpicking has been the oldest weed management strategy and is as old as the origin of agriculture. The hoe, cutlass or hand picking of weeds in taro fields has been costly, cumbersome and less attractive and also may need repeated practices depending on the dominant troublesome weeds, rainfall conditions, leaf blight disease severity and available labour/cost[10]. However, manual hand weeding operation is still the best and the most effective weed management strategy depending on labour availability and cost where its application is also adopted early enough at the critical period and at regular intervals of up to 3-4 times at 2 months intervals to ensure zero to less weed infestation in taro fields as the crop like other humid tropical crops shows high sensitivity to weed interference[1]. The regular weeding practice by hand weeding throughout the taro growth cycle apart from provision of weed-free field conditions, less leaf blight disease severity, more life span (more normal senescences) and improved yield, enhance easy harvesting and packing of harvested tubers and also less labour cost/requirements during post-harvest activities.

Biological weed management strategies: The use of bioagents of life and low growing crops, both leguminous and non-leguminous cover food crops such as pumpkin (*Cucurbita pepo*), egusi-melon (*Citrullus colocynthis*), fluted pumpkin (*Telfairia occidentalis*) and other intercrops could reduce weed intensity experienced by many taro farmers besides improving profitability, also assures against crops failure, improves soil conditions and less soil erosion problem[11]. The use of other soil cover /creeping crops such as sweet potato and groundnut has been in use in taro fields. Previous taro production under high intercropping, interpolating mixed cropping and soil cover with other creeping, twisting and low growing cover crops (polyculture systems) are good cultural practices for proper weed management and high crop yield irrespective of high microclimate conditions like low air circulation and sunlight penetration, high soil moisture and low soil air temperatures generated in the fields. Smothering/life cropping as the use of living plants to reduce the growth, development and reproduction of weed seeds through competition for growth resources especially light be effective in suppressing annual and perennial weeds[12]. Smother crops as a weed suppressive in nature were attributed to their allelopathic potential which fluted pumpkin, pumpkin, egusi melon etc are inclusive[13]. However, the present prevailing climate change associated with high erratic rainfall conditions and the devastating *Phytophthora* leaf blight disease under high air humidity and low night and daily temperature of 20-21°C and 25-28°C, respectively, makes the use of high climbing, creeping/planophile or twisting crops such as pumpkin and fluted pumpkin and other intercropping or interplanting systems unfavourable for taro production and therefore, should be avoided as weed management strategies in taro fields. These high luxuriant vegetative crops as intercrop or mixed crops in a taro field without regular frequent cutting/harvest can help in smothering of both weeds and taro, thereby resulting in more taro leaves, petioles and stem girth decay. Also, the use of fast-growing cover crops like egusi melon and cowpea as intercrops/mixed crops makes earthling up/re mounding practices not easily practicable which is a good wise and friendly agronomic operation that provide a fresh healthy soil microenvironment for improved tuber formation and total tuber yields. However, Barberi reported an allelopathic nature of fluted pumpkin and other cover crops in weed management[13]. Taro has lost its unique attributes as a shade, erratic rainfall and waterlogged tolerance and as well weed suppressive nature under the present prevailing climate change and *Phytophthora* leaf blight disease effect in taro fields.

Chemical weed management strategies: The application of herbicides has remained the most immediate and effective method of exterminating weeds at large scale taro production at an appropriate rate. The most highly recommended pre-emergence herbicides like primextra at 2-3 kg a.i ha^{-1}, prometryne 1.2 kg a.i ha^{-1}, Dalapon 3 kg a.i ha^{-1} and TCA+Ametryne, Atrazine, trifluraline are recommended for upland taro, while Nitrogen at 3-6 kg a.i ha^{-1} could be added to the irrigation water for wetland taro production[14]. Goal Tender 4F at 0.75 kg ha^{-1} is recommended for weed control in taro in South Eastern Nigeria[15]. Due to the limitation of manual hand weeding and the need to produce larger hectares of taro, the choice of herbicide treatment becomes imperative. In pre-emergence herbicides treatment, supplementary hand weeding is usually necessary where the taro cannot make total ground cover easily[1]. However, the environmentally unfriendly effects of herbicides such as contamination of underwater, soil/air pollution and food have created a serious psychological imbalance and speculation against injudicious and an uncontrolled wide spray of herbicides[16]. Moreso, herbicide spray failure most especially pre-emergence herbicide treatment on some troublesome weeds like *Cyperus* spp., *Imperata* spp., etc has been reported by many field crop workers irrespective of their herbicide spray experts and experiences[17]. Furthermore, the application of post-emergence and contact herbicides in taro field at the present outbreak of taro leaf blight disease with much leaves, petioles and stem girth decay/damage in addition to much high rainfall conditions are agronomically and economically unwise, labour intensive and unpleasant irrespective of high weeds infestation in taro fields during the growth periods.

Cultural practices/agronomic manipulation strategies: The adoption of some cultural practices and agronomic manipulation has been very essential field practice against taro pre/post-emergence weed competition. The following cultural/agronomic measures have been reported to reduce weed growth and development significantly, especially at the present global outbreak of *Phytophthora* colocasiae and less tolerant of taro to erratic rainfall and waterlogged conditions.

Crop rotation: Crop rotation has a preventive effect or both pre and post-emergence effect in taro production by reducing the number of mature weed seeds/weed bank, weed growth and development and spread of more weed seeds, reduction of some troublesome weeds and its proficiency. It has been reported that weeds, pests and diseases can often be easily managed significantly by crop rotation especially those high soil moisture love weeds that are highly associated with taro fields[1].

Proper taro inter and intra row spacing: The spacing of taro varies among the researchers and produces and depends on land availability, farmer's needs and planting cornel's size. The present outbreak of leaf blight disease has generated serious issues on the spacing of taro among all stakeholders of taro production due to the increased rate of weed infestation in taro fields and its final effect on crop yield loss. The varied planting space adopted by the producers has some bearing on plant intensity, TLB disease severity, crop yield and weed infestation. The aim of increasing plant intensity is to provide less space to weed to grow. Heavy stands with low plant intensity of taro will form crop canopy earlier, thereby reducing the penetration of light on the soil surface. Generally, weed growth is more in thinly populated with large/medium spacing as compared to thickly populated crops. However, the recommended close spacing of 0.5×0.5 m inter and intra row spacing by many researchers has been reported to promote TLB disease severity through rain splash but results in high yield/ha and low yield/individual stands[18]. Similarly, the wider spacing between plants 50×75 cm or medium spacing of 75×75 cm has been observed as a means of limiting disease spread through rain splash, winds movement, insect pests, thereby improving yield/ individual stand but reducing yield ha^{-1} [18]. However, the adoption of wider/medium spacing in taro production apart from reducing yield ha^{-1} promote more weed infestation which may enhance more leaves, petioles stem girth damage by TLB disease that may necessitate more weeding regimes. This suggests that the planting space to be adopted by producers depends on their produce needs on yield if all necessary weeding and disease management arrangements are taken into good measures. In general, wider spacing creates more area to be left for more weeds growth and development that must require more weed management schedules and labour/cost requirements for improved taro production.

Increasing weeding regimes: In the recent global effect of TLB disease, the disease itself acts as a defoliator or myco-herbicide to taro fields. *Phytophthora colocasiae* Racib likes Devine, a bio-herbicide (*Phytophthora palmivora*) but has been used to control strangler vine (*Morrenia odorata* lindl) in Florida. *Phytophthora colocasiae* results in high quantitative and qualitative losses of taro yield especially under the prevailing climate change associated with high rainfall conditions at the maximum growth stage of taro which also promotes high weed infestation in both thinly and thickly populated fields in widely and closely spaced fields, respectively. This suggests that the earlier recommended weeding regimes, 2 times by some researchers should be extended to 3-4 times hoe weeding regimes for 6-9 months growth cycle[3]. The suggested more weeding arrangements will create free weed conditions in taro fields, thereby reducing much weed competition for crop growth resources (light, space, soil, moisture, soil nutrients) and as well fewer leaves, petioles and stem girth and to some extent tubers severe decay/damage by TLB disease due to poor air movement and sunlight penetration resulting to poor tuber formation and general low yield. Further, due to the effect of TLB disease at the critical growth period of taro, the crop does not provide functional leaves and an effective crop canopy that can suppress the weed growth in both low and wider spaced fields. Therefore, weeds enjoy the more favourable environment in the present taro field production caused by TLB disease as compared to the past before the arrival of the disease where taro acts as a weed suppressive crop in either low or wider spaced pattern.

Cropping systems: Traditionally, intercropping, interplanting and home farming with other mixed cropping systems has been a common practice in taro production due to its unique tolerance to shade conditions, rainfall tolerant and as a part of agroforestry services[5]. Moreso, these cropping systems increase nutrition efficiency, reduce the risk of crops yield loss due to pests, disease and weather extremes, in short terms, but also improve soil fertility and slow down pathogen evolution more efficient use of vertical space and weed suppression, thereby increasing the life span of the resistant host plant, increase the quality and quantity of production[19-21]. However, these cropping systems with taro have harmed taro production since the outbreak of TLB disease. The cropping systems provide a shaded environment, the microenvironment of high soil air humidity or poor air movement and less sunlight penetration, more after raindrop effects which promote more TLB disease severity and subsequent unrestricted weed infestation problem in defoliated taro fields. The open fields cultivation system should be encouraged to reduce certain microenvironments which promote the disease severity, high weed infestation and also inoculums spread as crop intensity arising from the intercropping and interplanting system or mixed cropping has a significant bearing on the present type and amount of pests, weeds and disease development in recent taro fields[22].

Cropping season: Dry season cropping of taro should be encouraged where water supply is not a limiting factor as much erratic rainfall during raining reason cropping for rain-fed taro production promote high weed infestation most especially on the highly defoliated field by TLB disease thereby creating more open space for weed seeds germination, growth and development. Moreso, dry season cropping records fewer flushes of weeds as compared to rainfed taro where weed seeds germinate in many flushes which reduce the efficiency of weed management techniques. This explains why most larger-scale taro producers are fully engaged in wetland taro production to escape the TLB disease, less weed infestation and also to ensure food security all season round. Tarla *et al*.[23] reported that taro growers should undergo dry season cropping in December with an artificial water supply to escape the heavy disease pressure in rainy season planting.

Planting times: Weed-taro competition can be reduced significantly by way of an escape mechanism. Early season planting of taro around March-May suffers more flushers of a weed problem than late-season planting. Weeds in late season planting around June-July, can be controlled by delaying land clearing/preparation to allow weed seeds to germinate before land preparation, thereby reducing the weed intensity and biomass compared to early rain season planting where land clearing/preparation will be done in the dry season and also no or fewer weed seeds germination before land preparation or seedbed cultivation. Late season planting of taro help in reducing the population of all type of weeds and less labour requirement/cost and also less number of weeding periods throughout the growth cycle. The weed seeds which have been germinated before late planting can be turned into green manuring during land preparation through ploughing, harrowing and ridge/mound making or killed by contract herbicide before seedbed preparation. In late season planting, most of the weed seeds present in the field would germinate and can be destroyed during taro seedbed preparation. However, early rainy season planting will require more labour cost/requirements, regular weed schedule regimes, but more taro total tuber yield and less destruction by TLB disease and can be improved if other cultural practices such as optimum manure application of 30 t ha^{-1} poultry manure or 300 kg a.i ha^{-1} of N:P: k 15:15:15 fertilizer or mixed fertilizer rich in potassium (80 kg N: 20 kg P: 100 kg K), proper regular weeding arrangements of 3-4 times, proper pests and disease management, proper medium inter and intra row spacing of 75×75 cm proper tillage practice/cultivation, proper earthling up/drainage systems are taken into good measures[24-26].

Proper summer tillage practices: Tillage is used to uproot the germinating or germinated weed seedlings and in exposing the weed seeds from lower depth to the upper soil surface. Tillage also aids air circulation, proper organic matter incorporation in the soil, more soil water percolation, easy crop roots penetration, easy exposure of weed seeds or weed propagules to adverse environmental conditions (light and desiccation). Proper tillage practices during ploughing, harrowing and seedbed preparation will ensure no escape of weeds[27]. The escaped weed plant after all tillage operations must be uprooted by handpicking or other methods before seed formation. Moreso, the escaped weed plants due to poor herbicide spray techniques can be controlled by manual hand picking practices. Tillage can also be used to reduce seed banks and ensure preventive measures on earlier weeds growth and development in taro fields unlike where tillage practices are done without proper turning or killing of existing weeds.

Mulching practices: Mulches may be composed of plant materials or synthetic materials made by plastic sheets. Mulches or mulch materials are derived from different types of materials such as wheat straw, rice husk/straw, plastic films (black or white), dried grasses, wood shaves/sawdust, sandstones, newspapers, oil palm bunch wastes, coconut husk, etc[28,29]. Mulch materials provide a better soil environment for crops, increase plant-available soil water, moderate soil temperatures, improve soil organic matter contents/fertility, increase soil porosity and infiltration rate during intensive rain and control run-off and erosion and as well suppresses weed growth, alter the soil microenvironment and improve crop growth and yield[5,30-33]. The role of mulches as weed suppressive in taro fields depends on the thickness of the mulches, area coverage around taro stands that will prevent light penetration to the existing weed seeds in the fields. The 5-10 cm thickness of organic materials has been in good practice for good weed suppression in taro fields depending on available mulch materials.

Integrated weed management strategies (IWMS): The judicious adoption of combined weed management strategies have been presently gaining more attention by many tropical food crop producers, researchers and consumers. Weeds like other crop production limiting factors such as soil water content, disease, pests and nutrients are best managed through integrated strategies, especially at the present high demand for organically produced food crops. Integrated weed management strategies help to achieve better weed suppression, thus reducing competition, increased availability of crop growth resources and exposure of taro plant to full sunlight penetration paving way for the development of higher leaf area per plant and final higher total tuber yields.

Generally, no single method of weed management strategy can adequately meet the needs of any crop all the time. Therefore, the integration of various weed management strategies has been recommended to improve the health conditions of taro such as proper tillage, proper spacing, regular weeding regimes, crop, rotation, controlled use of herbicides with supplementary hoe weeding, adoption of well-spaced cover crops like fluted pumpkin at 30, 000 ha^{-1} or melon at 40,000 ha^{-1} during intercropping systems, adoption of open field location, proper pests and disease management, adoption of ridging or mounding bed preparation and re-mounding to improve air movement and drainage and as well reduce weed pressure. Integrated use of weed management measures results in satisfactory weed suppression than the use of a single control measure[9]. The adoption of any single method may not be an effective and sustainable way to manage weeds in taro fields at the present outbreak of devastating *Phytophthora* leaf blight disease and climate change where taro has lost its unique attributes as shade, erratic rainfall and waterlogged tolerantly and also as weed suppressive in nature.

Due to recent effects of TLB disease and increasing effects of climate change on rainfall conditions, the integration of the following major weed management options like use of medium spacing of 75×75 cm, regular weeding regimes of 3-4 times, pre-emergence herbicide spray followed by more supplementary hoe/hand weeding schedule regimes, open field location, regular/frequent harvesting of the fluted pumpkin were intercropped with taro especially male stands and, less incorporation of other cover crops or high climbing/trailing crops like pumpkin, sweet potato, egusi melon and also other vegetable crops, etc are recommended for normal growth, normal senescence/normal maturity and improved total tuber yields in taro fields.

CONCLUSION

Weed management is a major cultural operation in the production cycle of taro. Weeds have drastically caused yield reduction in taro at the present outbreak of *Phytophthora colocasiae* and increasing rate of rainfall condition which can be effectively managed by many alternative control strategies. However, no single management measure is adequate to achieve complete control of weed infestation. The adoption of an integrated weed management approach should be an ideal strategy against high weed infestation in the present taro production cycle.

SIGNIFICANCE STATEMENT

This study provides information on the available strategies which are instrumental in managing high weed infestations in taro field. Defoliation of taro caused by the outbreak of *Phytophthora colocasiae* leaf bight disease and climate change leads to high weed infestation in taro field and consequently yield losses if not properly managed. This review study will help the farmers to adopt taro leaf blight disease and climate change resilience practices through proper weed management to improve yield in taro fields and increase the interest of the society in taro farming as well as improve the economy of the cultivating zones and help solve the problem of food crisis.

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