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Weed persistence, crop resistance and herbicide phytotonic effects in cowpea (*Vigna unguiculata* [L] Walp) under various weed control treatments in Kano, Nigeria

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ABSTRACT

The yield of cowpea (var. IT99K-573-1-1) was tested in a field experiment using 12 different weed control treatments during the wet seasons of 2019 and 2020. The results showed that hoe weeding at 3 and 6 WAS had the highest weed persistence index, crop resistance index, and agronomic management index, closely followed by pendimethalin 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS, and metolachlor 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS. The most effective phytotonic practices were hoe weeding at 3 and 6 WAS, pendimethalin 2.0 kg a.i.ha^{-1} *fb* SHW at 6, and metolachlor 2.0 kg a.i.ha^{-1} *fb* SHW at 6. The best weed control methods for cowpea production from environmental point of view, were metolachlor at 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS and pendimethalin at 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS. Lower persistence of escaped weeds were seen with pendimethalin at 2.0 kg a.i.ha$^{-1\ fb}$ SHW at 6 WAS and metolachlor at 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS, indicating that these treatments had a broader weed-controlling impact than the other treatments.

***Keywords*:** Agronomic management index, Crop resistance index, Phytotonic effect, Weed persistence index, *Vigna unguiculata*

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1. INTRODUCTION

The cowpea (*Vigna unguiculata* (L) Walp) is an essential source of food for humans in poor, arid regions. The crop can also be fed to animals as feed. Its grain is consumed as inexpensive source of nutritional protein, while the tender leaves and immature pods are also eaten as vegetables (Dugje *et al*., 2009; Alemu *et al*., 2016). Additionally, the plant acts as livestock fodder (Belay *et al*., 2017). Nigeria is the continent's top cowpea grower, where the crop provides a living for many subsistence farmers (Neya *et al*., 2015; FAO, 2018). This crop's average production falls well short of its potential on a regular basis, which can be linked to a variety of biotic and edaphic causes. But out of all of these, weed infestation seems to be the most important biological restriction. Weeds have been identified as a significant negative constraint because they cause biotic stress, which prevents this valuable crop from realizing its genetic yield potential. According to Adigun *et al*. (2014), they control the majority of crop production methods and result in significant losses (25-60%) as a result of their involvement as opposed to insect pests and diseases pathogens. In addition to directly reducing crop quantity and quality due to competition for scarce growth nutrients, they act as substitute hosts for a number of disease pathogens (Abraham *et al*., 2020). In order to prevent economic losses, control measures are therefore necessary (Mahajan *et al*., 2014; Srinivasarao *et al*., 2014; Costa *et al*., 2017).

Manual weeding faces difficulties throughout the crucial stage of weed interference, including difficulties with time management, cost, drudgery, and labor scarcity. The only alternative left is to use herbicide in the right doses and mixtures to completely eradicate the weed population. Due of the diverse range of weeds, the herbicide alone frequently does not offer sufficient control. The efficacy of the herbicides could be improved, though, if supplemented with periodic hoe weeding. When applied to crops, herbicides often have either a phytotoxic or phytotonic effect, with the former indicating a detrimental effect and the latter being a beneficial effect. The phytotonic effect of herbicides on direct-seeded rice has been documented by Mishra *et al*. (2016). This area of weed studies has not received much attention. Therefore, in order to increase productivity, it is important to assess how well weed control treatments affect cowpea's phytotonic action and weed persistence.

2. MATERIALS AND METHODS

The experiment was conducted during the wet season of 2019 and 2020 at the Research and Teaching farm of the Faculty of Agriculture, Bayero University Kano, in a randomized complete block design with three replicates. The soil at the experimental site was sandy loam with low accessible N (0.06 g kg^{-1}), low levels of P (4.87 g kg^{-1}) and medium levels of K (0.32 g kg^{-1}).

The effectiveness of twelve different weed control strategies using various herbicides alone, in combination, or in addition to hoe weeding on cowpea (var. IT99K-573-1-1) was assessed. Every year, the crop was seeded in the first week of July at a seed rate of 75 kg ha^{-1}, and treated two weeks later with NPK (15:15:15) and SSP (18%) at a rate of 20 kg N, 40 kg P_2O_5, and 20 kg K_2O ha^{-1}. Herbicidal treatments were applied as per treatment. The details of the treatments were as follows: weedy check (control), hoe weeding @ 3 & 6 weeks after sowing (WAS), metolachlor at 2.0 kg a.i.ha^{-1}, imazethapyr at 3.0 kg a.i.ha^{-1}, pendimethalin at

2.0 kg a.i. ha^{-1}, pendimethalin at 3.0 kg a.i ha^{-1}, pendimethalin 1.0 + imazethapyr 1.0 kg $a.i.ha^{-1}$, metolachlor 1.5 + pendimethalin 1.5 kg $a.i.ha^{-1}$, imazethapyr 1.0 + pendimethalin 1.0 kg $a.i.ha^{-1}$ + SHW at 6 WAS, metolachlor 1.5 + pendimethalin 1.5 kg $a.i.ha^{-1}$ + SHW at 6 WAS, metolachlor at 2.0 + SHW at 6 WAS, pendimethalin at 2.0 + SHW @ 6 WAS. Data collected were subjected to analysis of variance (ANOVA) and treatment means were separated using Student Newman-Keuls-test (SNK) at 5% level of probability.

$$\text{Weed persistence index (WPI)} = \frac{\text{Dry weight of weeds in treated plot}}{\text{Dry weight of weeds in control plot}} \times \frac{\text{Weed count in the control plot}}{\text{Weed count in the treated plot}}$$

$$\text{Crop resistance index (CRI)} = \frac{\text{Crop dry matter in treated plot}}{\text{Crop dry matter in control plot}} \times \frac{\text{Weed dry matter in weed control plot}}{\text{Weed dry matter in treated plot}}$$

$$\text{Agronomic management index (AMI)} = \frac{\text{\% increase in yield over control} - \text{\% reduction of weeds}}{\text{\% control of weeds.}}$$

3. RESULTS AND DISCUSSION

3. 1. Weed flora composition

The floristic composition of the experimental site was dominated with broad-leaf weeds like *Mitracarpus villosus, Ageratum conyzoides, Senna obtusfolia, Leucas martinicensis, Cyanotis lanata, Spermacoce octoden, Acanthospermun hispidum, Celosia leptostachya* and grasses like *Cynodon dactylon* and *Panicum repens*. The dominant sedges observed were *Cyperus rotundus* and *Cyperus esculentus*. Other weeds observed in lower density were *Tephrosia linearis, Corchorous tridens, Ipomoea eriocarpa, Anthephora ampullaceal* and *Phyllanthus niruri.*

3. 2. Weed density and Weed biomass

Weed control measures in both seasons led to a noticeable change in weed density (Table 1). Highly significantly ($P \leq 0.01$) lower weed densities of 10.33, 10.67, and 11.67 n m^{-2} were noticed with hoe weeding at 3 and 6 WAS, pendimethalin, and metolachlor each at 2.0 kg $a.i.ha^{-1}$ *fb* SHW at 6 WAS, though at par with metolachlor 1.5 + pendimethalin 1.5 kg $a.i.ha^{-1}$ *fb* SHW at 6 WAS in the 2019 season. On the other hand, hoe weeding at 3 and 6 WAS, which was also at par with other weed control treatments, significantly ($P \leq 0.01$) resulted reduced weed density in the 2020 season and the pooled analysis. Meanwhile, significantly maximum weed density was observed in weedy check plots (49.0, 50.0 and 49.50 n m^{-2}) in both the years (2019 and 2020) and the pooled data. The weed biomass observed during cowpea harvest is shown in Table 1. The biomass of the weeds was significantly affected by various weed management techniques. In 2019, 2020, and the pooled analysis, respectively, hoe weeding together with other weed management methods produced noticeably less weed biomass than the weedy check, which produced greater weed biomass. Nevertheless, supplemental hoeing is often a preferable kind of treatment. This could be because alternative herbicidal treatments, either alone or in combination with hoe weeding, were able to control both early and late flushes of weeds, hence reducing their population, whereas preemergence herbicide alone or in mixture only controlled the early flushes of weeds.

Table 1. Effect of different weed control measures on weed density and weed biomass of cowpea at harvest during 2019 and 2020 wet cropping season

Treatment	Rate (kg ha^{-1})	Weed density (n m^{-2})			Weed dry weight (g m^{-2})		
		2019	2020	Pooled	2019	2020	Pooled
Weedy check	-	49.00^{a}	50.00^{a}	49.50^{a}	137.27^{a}	135.33^{a}	136.30^{a}
Hoe weeding	3 and 6 WAS[1]	10.33^{f}	14.00^{c}	12.17^{e}	27.43^{bc}	30.53^{e}	28.98^{c}
Metolachlor	2.0	25.67^{b}	24.33^{bc}	25.00^{b}	42.73^{b}	57.67^{b}	50.20^{b}
Imazethapyr	3.0	25.00^{b}	23.00^{bc}	24.00^{b}	43.00^{b}	59.33^{b}	51.17^{b}
Pendimethalin	2.0	14.67^{e}	28.67^{b}	21.67^{bcd}	32.13^{bc}	52.33^{bc}	42.23^{bc}
Pendimethalin	3.0	20.67^{cd}	21.00^{bc}	20.83^{bcd}	30.67^{bc}	50.00^{bc}	40.33^{bc}
Imazethapyr + Pendimethalin	1.0 + 1.0	22.33^{c}	15.67^{c}	19.00^{b-e}	27.67^{bc}	46.00^{cd}	36.83^{bc}
Metolachlor + Pendimethalin	1.5 + 1.5	18.33^{d}	18.00^{bc}	18.17^{b-e}	26.00^{bc}	43.60^{cd}	34.80^{bc}
Imazethapyr + Pendimethalin	1.0 + 1.0 + SHW[2]	18.33^{d}	18.00^{bc}	18.17^{b-e}	24.00^{c}	38.33^{de}	31.17^{c}
Metolachlor + Pendimethalin	1.5 + 1.5 + SHW	13.33^{ef}	23.00^{bc}	18.17^{b-e}	23.33^{c}	36.33^{de}	29.83^{c}
Metolachlor	2.0 + SHW	11.67^{f}	18.33^{bc}	15.00^{cde}	20.00^{c}	29.33^{e}	24.67^{c}
Pendimethalin	2.0 + SHW	10.67^{f}	16.67^{bc}	13.67^{de}	19.87^{c}	27.67^{e}	23.77^{c}
P of F		<.001	<.001	<.001	<.001	<.001	<.001
SE±		0.802	2.478	1.885	4.00	2.581	4.37

Means followed by the common letter (s) in a in column are not significantly different at 5% according to Student - Newman-Keuls Test (SNK).
[1]WAS = weeks after sowing; [2]SHW = Supplementary hoe weeding

Kumar *et al*. (2016) and Punia & Tehlan (2017) both noticed the effectiveness of herbicidal treatment combined with periodic hoe weeding, which led to lower weed density and weed biomass.

3. 3. Crop dry matter production

The overall dry production of the crop (Table 2) indicated that the hoe weeding at 3 and 6 WAS produced maximum dry matter (600 g m^{-2}) which was closely followed by pendimethalin and metolachlor each at 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS, metolachlor 1.5 + pendimethalin 1.5 *fb* SHW at 6 WAS and imazethapyr 1.0 + pendimethalin 1.0 *fb* SHW at 6 WAS (502.7, 496.7, 463.3 and 456.7 g m^{-2}) in decreasing order in the 2019 season. Similar to how pendimethalin and metolachlor, each at 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS, significantly produced higher dry matter (573.0 and 558.3 g m^{-2}) followed by the other treatments that caused decreased dry matter in the 2020 season, hoe weeding at 3 and 6 WAS significantly produced maximum dry matter (598.7 g m^{-2}). Weedy check, on the other hand, significantly ($P \leq 0.01$) produced less dry matter (291.0, 303.7 and 297.3 g m^{-2}) in the 2019 and 2020 seasons, as well as in the pooled analysis.

Dry matter production is largely a function of photosynthetic surface, which can be affected by weed management techniques. As a result, treatments with fewer weed populations can produce more dry matter, possibly because there is less competition for growth resources, more leaves and branches per plant, and a cumulative effect that results in maximum dry matter production. The severe weed competition that led to a lower utilization of growth resources for dry matter production and partitioning in both seasons and the pooled analysis may be the cause of the lower dry matter obtained in weedy checks. The results of this study corroborated those of Sangeetha *et al*. (2012) and Smita *et al*. (2014), who both observed an increase in dry matter due to successful weed removal.

3. 4. Grain yield

The results for grain yield (Table 2) indicated that hoe weeded twice at 3 and 6 WAS, pendimethalin and metolachlor each at 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS recorded significantly higher yields of 699.3, 699.3 and 688.0 kg ha^{-1}, which were closely followed by metolachlor 1.5 + pendimethalin 1.5 *fb* SHW at 6 WAS and imazethapyr 1.0 + pendimethalin 1.0 *fb* SHW at 6 WAS (658.3 and 649.0 kg ha^{-1}) compared with the rest of the weed control treatments that resulted in decreased grain yield in the 2019 season. Similarly, in hoe weeded plots, pendimethalin and metolachlor at 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS, pendimethalin 1.5 *fb* SHW at 6 WAS, and imazethapyr 1.0 *fb* SHW at 6 WAS gave significantly greater yields of 720.0, 717.7, 716.0, 698.7, and 699.0 kg ha^{-1} respectively, compared to the other treatments that resulted in decreased yields in the 2020 season. The pooled analysis, on the other hand, shows that hoe weeded plots, which were at par with pendimethalin and metolachlor each at 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS, pendimethalin 1.5 *fb* SHW at 6 WAS and imazethapyr 1.0 + SHW at 6 WAS, produced higher grain yields in comparison to other weed control treatments, with yield increases of between 221.9 and 233.68% over the weedy check that significantly ($P \leq 0.01$) produced the lowest grain yield of 301.3, 306.0, and 303.7 kg ha^{-1} in 2019, 2020, and the pooled analysis, respectively. The resultant increased in yield could be attributed to higher dry matter produced and partition to seed production in weed treated plots which could also be associated to effective weed management.

Table 2. Effect of different weed control measures on crop dry matter and grain yield of cowpea harvest during 2019 and 2020 wet cropping season

Treatment	Rate (kg ha^{-1})	Total dry matter of plants (g m^{-2})			Grain yield (kg ha^{-1})		
		2019	2020	Pooled	2019	2020	Pooled
Weedy check	-	291.0^{g}	303.7^{f}	297.3^{g}	301.3^{f}	306.0^{f}	303.7^{f}
Hoe weeding	3 and 6 WAS[1]	600.0^{a}	598.7^{a}	599.3^{a}	699.3^{a}	720.0^{a}	709.7^{a}
Metolachlor	2.0	365.0^{f}	368.7^{e}	366.8^{f}	510.3^{e}	525.7^{e}	518.0^{e}
Imazethapyr	3.0	367.3^{f}	373.3^{e}	370.3^{f}	520.0^{e}	533.3^{ce}	526.7^{e}
Pendimethalin	2.0	398.7^{e}	396.3^{de}	397.5^{def}	560.3^{d}	562.7^{cd}	561.5^{d}
Pendimethalin	3.0	405.0^{e}	405.7^{de}	405.3^{de}	564.7^{d}	567.7^{c}	566.2^{d}
Imazethapyr + Pendimethalin	1.0 + 1.0	377.3^{f}	389.3^{de}	383.3^{ef}	586.3^{c}	634.0^{b}	610.2^{c}
Metolachlor + Pendimethalin	1.5 + 1.5	426.0^{d}	422.7^{cd}	424.3^{d}	593.7^{c}	639.3^{b}	616.5^{c}
Imazethapyr + Pendimethalin	1.0 + 1.0 + SHW[2]	456.7^{c}	444.0^{c}	450.3^{c}	649.0^{b}	699.0^{a}	674.0^{b}
Metolachlor + Pendimethalin	1.5 + 1.5 + SHW	463.3^{c}	452.3^{c}	457.8^{c}	658.3^{b}	698.7^{a}	678.5^{ab}
Metolachlor	2.0 + SHW	496.7^{b}	558.3^{b}	527.5^{b}	688.0^{a}	716.0^{a}	702.0^{ab}
Pendimethalin	2.0 + SHW	502.7^{b}	573.0^{ab}	537.8^{b}	693.3^{a}	717.7^{a}	705.5^{ab}
P of F		<.001	<.001	<.001	<.001	<.001	<.001
SE±		5.16	9.97	9.13	6.07	9.99	8.74

Means followed by the common letter (s) in a in column are not significantly different at 5% according to Student- Newman-Keuls Test (SNK).
[1]WAS = weeks after sowing; [2]SHW = Supplementary hoe weeding

The subsequent increase in yield may be ascribed to greater dry matter produced and allocated to grain production in weed-treated plots, which could possibly be connected to efficient weed management. The results of this study are consistent with the findings of Panda *et al*. (2015), Gupta *et al*. (2016), Omisore *et al.* (2016) & Kumar and Singh (2017).

3. 5. Weed control efficiency, Weed index, Weed persistence index, Crop resistance index, Agronomic management index

The result (Table 3) showed that hand weeding (78.3) produced the highest WCE, followed by metolachlor and pendimethalin each at 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS (72.47 and 72.17). While among the herbicidal treatments, metolachlor and imazethapyr were applied at 2.0 and 3.0 kg a.i.ha^{-1} each, respectively, produced the lowest WCE (47.08 and 50.73). In a similar manner, the weed index (WI) was lowest with hoe weeded, then metolachlor and pendimethalin at each 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS, metolachlor 1.5 + pendimethalin 1.5 *fb* SHW at 6 WAS, and imazethapyr 1.0 + pendimethalin 1.0 *fb* SHW at 6 WAS.

The weed persistence index (WPI), indicating relative dry matter accumulation of weeds per count in comparison to control (Table 3), indicated that the hand weeding resulted in a higher persistence index (2.04) closely followed by pendimethalin at 2.0 *fb* SHW at 6 WAS (1.86) and metolachlor at 2.0 + SHW (1.81), indicating resistance of escaped weeds to control measures. Lower weed persistence was observed with metolachlor at 2.0 kg a.i.ha^{-1} (0.85) and imazethapyr at 3.0 kg a.i.ha^{-1} (0.87), indicating a broad spectrum effect in weed control.

Table 3. Effect of different weed control measures on various weed indices of cowpea at harvest pooled analysis

Treatment	Rate (kg ha^{-1})	Weed indices				
		WCE	WI	WPI	CRI	AMI
Weedy check	-	0.00^{i}	54.15^{a}	0.45^{d}	0.99^{h}	0.00^{j}
Hoe weeding	3 and 6 WAS[1]	78.53^{a}	0.00^{f}	2.04^{a}	10.72^{a}	0.44^{a}
Metolachlor	2.0	47.08^{gh}	38.70^{b}	0.85^{c}	2.14^{g}	0.12^{i}
Imazethapyr	3.0	50.73^{g}	36.35^{bc}	0.87^{c}	2.37^{g}	0.16^{h}
Pendimethalin	2.0	58.50^{f}	34.00^{cd}	1.05^{bc}	4.05^{f}	0.20^{g}
Pendimethalin	3.0	57.40^{f}	30.47^{d}	1.08^{bc}	4.40^{f}	0.23^{f}
Imazethapyr + Pendimethalin	1.0 + 1.0	60.00^{def}	31.82^{d}	1.11^{bc}	5.88^{e}	0.26^{e}
Metolachlor + Pendimethalin	1.5 + 1.5	60.00^{def}	30.47^{d}	1.13^{bc}	6.25^{e}	0.29^{d}
Imazethapyr + Pendimethalin	1.0 + 1.0 + SHW[2]	66.10^{b-e}	22.20^{e}	1.35^{b}	8.15^{d}	0.32^{c}
Metolachlor + Pendimethalin	1.5 + 1.5 + SHW	66.50^{b-d}	23.03^{e}	1.45^{b}	8.58^{c}	0.35^{b}
Metolachlor	2.0 + SHW	72.47^{b}	22.95^{e}	1.81^{a}	9.11^{b}	0.42^{a}
Pendimethalin	2.0 + SHW	72.17^{bc}	22.88^{e}	1.86^{a}	9.42^{b}	0.42^{a}
P of F		<.001	<.001	<.001	<.001	<.001
SE±		1.976	1.199	0.1011	0.145	0.007

Means followed by the common letter (s) in a in column are not significantly different at 5% according to Student-Newman-Keuls Test (SNK). WAS[1] = weeks after sowing; SHW[2] = Supplementary hoe weeding, WCE = Weed control efficiency, WI = Weed index, WPI = Weed persistence index, CRI = Crop resistance index, AMI = Agronomic management index

According to the crop resistance index (CRI) (Table 3), hoe weeding at 3 and 6 WAS resulted in the highest crop resistance (10.72), which was followed by pendimethalin and metolachlor at 2.0 kg a.i.ha^{-1} each *fb* SHW at 6 WAS, and metolachlor 1.5 + pendimethalin 1.5 *fb* SHW and imazethapyr 1.0 + pendimethalin 1.0 *fb* SHW (9.42, 9.11, 8.58, and 8.15), indicating a less harmful effect of weeds on the crop as compared to other treatments.

The agronomic management index (AMI) (Table 3) demonstrated the impact of herbicides on environmental parameters, which revealed that hand weeding at 3 and 6 WAS recorded higher AMI which may be due to phytotonic effect (0.44), which is similar to herbicidal treatments of pendimethalin and metolachlor at 2.0 kg a.i.ha^{-1} each *fb* SHW at 6 WAS compared to application of metolachlor at 2.0 and imazethapyr at 3.0 kg a.i.ha^{-1} that resulted in lower (0.16 and 0.12) values of AMI, indicating its harmful effect on non-target factors. In general, the reduction in weed biomass, weed count, and WI, together with higher WPI, WCE, CRI, and AMI values achieved in hoe-weeded plots and herbicidal treatments of pendimethalin and metolachlor at 2.0 kg a.i.ha^{-1} each *fb* SHW at 6 WAS, contributed to the improvement in cowpea yield. Ahmed and Chauhan (2014), Mishra *et al*. (2016) and Shittu *et al*. (2021a & 2021b) found similar results of manual weeding in terms of WCE, CRI, and AMI, which were closely followed by herbicidal treatments that resulted in higher grain yield and exerted some phytotonic effects.

4. CONCLUSIONS

It can be concluded that hoe weeding has a greater phytotonic effect than herbicides. Herbicides like pendimethalin 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS and metolachlor 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS have demonstrated phytotonic effects in cowpea. In comparison to those that are complemented by hoe weeding, pre-emergence herbicides like pendimethalin, metolachlor, and imazethapyr applied alone, regardless of the rates, do not provide season-long weed control. The weed persistence index and crop resistance index was maximum in hand weeding treatment followed by pendimethalin 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS and metolachlor 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS. The application of pendimethalin at 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS and metolachlor 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS were the next-highest treatments after hoe weeding in terms of weed persistence index and crop resistance index, respectively. Therefore, in the Sudan region of Nigeria, the application of metolachlor at 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS and pendimethalin at 2.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS were the most effective herbicidal treatments for cowpea.

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